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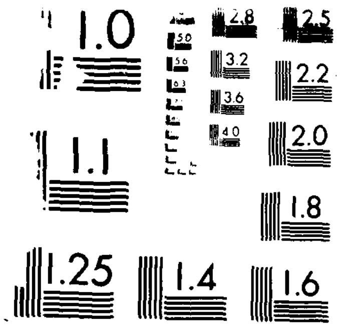

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THESIS

MODELS FOR AVENUE OF APPROACH GENERATION
AND
PLANNING PROCESS FOR GROUND COMBAT FORCES

Douglas L. Fletcher

September 1986

Thesis Advisor: Samuel H. Parry

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Models for Avenue of Approach Generation and Planning Process for Ground Combat Forces

by

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ABSTRACT

This thesis extends the development of the Airland Research Model (ALARM), an on-going research effort at the Naval Postgraduate School, in the areas of generating tactical boundaries through avenue of approach generation and the development of a plan over time for the commitment of ground combat forces. Terrain analysis on the basis of flow rate is used to develop zones of action on a network. Through these zones of action, avenues of approach are determined to represent the movement of regimental size units. Development of a defensive plan for ground combat forces is based on the generalized value system (GVS), which is an integral part of ALARM. The plan produced is a series of missions over a planning time horizon for the units of a brigade in the defense, planning to fight a motorized rifle division.

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I. INTRODUCTION

A. THE AIRLAND RESEARCH MODEL

This thesis represents an ongoing development of the Airland Research Model (ALARM) at the Naval Postgraduate School. ALARM will model corps-level combat under Airland Battle doctrine.

The doctrine for Airland Battle is characterized by an extended, integrated battle involving the case of all available air and land forces. It is extended because the battle in part is fought prior to and beyond the Forward Line of Troops (FLOT). Inherent in this doctrine is the simultaneous fighting of enemy forward forces and the deep attack of follow-on echelons. One of the primary objectives of the Airland Battle is to delay, disrupt, or destroy enemy follow-on forces before they can join in close combat. Operations at extended ranges are foundations of this doctrine.

The research model ALARM is an effort to explore different methodologies previously not incorporated in production military models. ALARM is designed to operate in a systemic mode, without a man-in-the-loop. In order to achieve this systemic model, a set of rule-based systems is being developed to represent the planning process associated with combat decision making. These rule-based systems must be converted to algorithms to represent the decision making process. These algorithms would simulate decisions such as force deployment, task organization of combat forces, and generation of tactical control measures. Furthermore, in terms of planning, these algorithms should develop missions based upon perceived knowledge of enemy actions over a planning time horizon. Models which represent the planning process are currently the major emphasis of research, and specifically the purpose of this study. These planning models are only a part of the overall architecture of ALARM. In general ALARM is composed of execution models and planning models. Execution models are those which simulate the actual force on force conflict. The planning models are those which operate in parallel to the execution models. The planning model uses information from the execution model. From this information a plan for the commitment of units over time is determined. This plan is then returned to the execution model and implemented. This type of plan is called the macro plan. The planning model associated with making decisions on an immediate basis produces a micro plan. In addition to planning models there are models such as the intelligence model and the logistics model which represent corresponding intelligence gathering and supply/maintenance activities respectively, on the battlefield. These models are currently being developed at the Naval Postgraduate School. These models also provide information to the planning model based on the current situation of forces in the execution model.

B. PURPOSE

The purpose of this thesis is to extend the development of the planning model in the area of ground force mission generation. Specifically the goals of this thesis are to develop a means of generating tactical boundaries through identification of avenues of approach, and to develop a decision methodology to generate ground force missions during the planning sequence.

This effort will incorporate several methodologies previously explored by ALARM research. The Generalized Value System (GVS) developed by Kilmer [Ref. 1] provides a basis for determining the value or worth of entities on the battlefield. The use of network methodology to model terrain was developed by Craig [Ref. 2] and McLaughlin [Ref. 3].

C. METHODOLOGY

Methodology here refers to a logical stepwise progression of research to render a possible solution to a problem. In solving a problem one needs to understand the basis for the problem. Our problem is to model those procedures used by real world commanders and staffs to develop plans for the commitment of units over time. A brief review will explain the planning process used currently, along with factors having an impact on this process. In addition a review of previous work done on ALARM will provide the basic constructs upon which this study is based. After clarifying what is to be modeled and the previous work on which the model is based, this study will describe the analysis and production of planning algorithms needed in order to accomplish the goals previously set forth. Implementation of these planning algorithms will be accomplished through the use of examples supported by computer simulation using the planning methodology proposed as the essential construct. Finally the results of the study will be summarized along with possible future directions of research within this area.

D. SCOPE OF THE THESIS

Since ALARM is a systemic model, decision processes have to be developed to simulate those which occur in the "real world". The development of a planning methodology is such a process. Specifically the final goal of ALARM is to represent a force-on-force conflict between a U.S. Corps and a Soviet Front. ALARM involves multi-command level interaction. The interaction between levels is demonstrated by limiting the scope of the problem to two levels. These levels are chosen in this study to be the U.S. (Blue) brigade and battalion. Furthermore this study is concerned with the planning process of the Blue forces, due to the difference in processes used by Soviet ground forces. This difference arises from a contrast in military capability, technology, and national objectives. When considering the Blue planning process it is important to note that the most likely commitment of Blue forces in the ALARM environment is in a defensive role. Therefore this study will concentrate on the defensive planning process. Although this research will concentrate on defensive operations a brief evaluation of Blue offense and Red (Soviet) missions will also be included. An area that will not be a subject of explicit research is that of data structures and flows from an execution model to a planning model. This subject is a concurrent effort by Major Gaylon Smith at the Naval Postgraduate School.

II. BACKGROUND

A. FOUNDATIONS OF TACTICAL PLANNING (DEFENSE)

1. Information Required for Planning

Understanding the planning concepts which are to be modeled requires a need to review the military planning process as it relates to defensive operations. In the defense, formation of a tactical plan must consider doctrinal issues of "how to fight" along with what is known as METT-T [Ref. 4]. METT-T stands for mission, nature of the enemy, friendly troop unit capabilities, terrain conditions and time available.

Mission analysis usually has the primary goal of identifying specified and implied tasks. Implied means unspecified tasks essential for a subordinate unit to accomplish the mission. An example would the requirement to conduct an extended road march accross a division sector to occupy an attack position in order to conduct an attack. The next element of METT-T considers the enemy forces. It is necessary to know the size and composition of his forces and what they have the capability or intent to do. Capabilities of friendly troop units are critical to the planning process. Resource availability can determine the feasibility of any defensive plan. Terrain is probably the first thing a commander considers after receiving a mission. All elements in the planning process are somehow linked to terrain. The essentials consider observation, cover and concealment, obstacles, key terrain and avenues of approach. An additional element of terrain that impacts on the tactical plan is weather. Visibility and movement can be greatly altered due to the weather and therefore can severely impact on the tactical planning process. Time is another element that impacts on the tactical plan. Here it refers to the amount of time allowed to a commander to plan and prepare to accomplish a mission.

2. Fundamentals of the Defense

A properly planned and executed defense can defeat an attack by a numerically superior enemy. The defender must select terrain which is advantageous to him, while exposing the attacker to the defender's firepower. The terrain advantages must be reinforced by mines, obstacles and improved through preparation of the fighting positions. The fundamental requirements for planning and conducting defensive operations are six-fold [Ref. 5].

- The first is to understand the enemy, by knowing his capabilities and limitations.

- The second is to "see the battlefield". Seeing the battlefield means that the decision maker must have up to date information about the shape of the battlefield, such as location of enemy and friendly units.
- Thirdly the advantages of the defender should be exploited. Through efforts to properly prepare the terrain a defending force can defeat a numerically superior enemy.
- The fourth fundamental of maximizing effectiveness of key weapons considers organizing the defense around the weapons most effective against the principal threat.
- The fifth fundamental of concentrating combat power at critical times and places is perhaps the most crucial because it must answer the critical question of when to use certain friendly assets.
- The last fundamental is to fight as a combined arms team. This implies that the battle will be fought through synchronization of all combat assets available to exploit the strength of each type of unit.

3. Organization of the Defense

Corps, divisions, and brigades fight a unified defensive battle within an organizational framework consisting of five elements. The first of these is deep battle operations in the area of influence. This is in keeping with the role of deep attack in the Airland Battle to delay, disrupt or destroy uncommited forces before their combat potential can be brought to bear against friendly forces. Secondly, there is a covering force operation in the area of influence to gain and maintain contact with attacking enemy forces, to develop the situation, and to delay or defeat the enemy's leading fighting forces. The next is the primary effort in the main battle area (MBA). Whatever the concept of operation, the decisive defensive battle is fought either at the forward edge of the battle area (FEBA) or within the main battle area. Then, reserve operations are conducted either in the MBA or in the covering force area in support of the main effort. Lastly rear area combat operations are considered.

A simple way to consider the flow of organization is through the following example. Once a division commander has decided where he intends to employ his forces, brigades are designated to control battalions defending in the MBA. The division commander designates sectors in which brigade commanders are expected to fight their forces. Brigade commanders in turn organize for the defense by assigning sectors or battle positions to subordinate battalions or task forces. These sectors at each level are constrained and shaped through the use of control measures which represent analysis of METT-T. Control measures are required for proper organization and control of defensive operations. Since there are many different types of control measures linked to specific types of operations, only those essential to the defensive planning process will be discussed. The following examples are used to illustrate the elements of organization of the defense (see Figure 2.1).

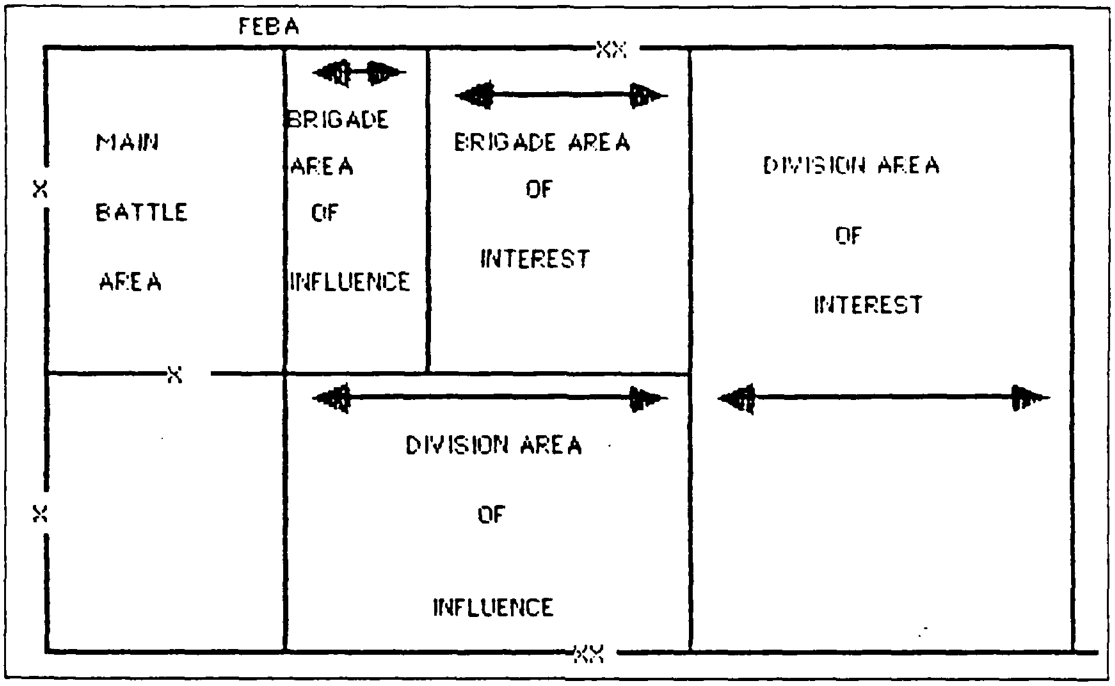

Figure 2.1 Organization of the Defense.

Boundaries define areas of tactical responsibility. Some of these boundaries in the defense are the FEBA, area of interest, and area of influence. Area of interest is that area of the battlefield which contains enemy forces capable of affecting current and future operations of each particular command level. The portion of the battlefield where a commander is capable of acquiring and fighting enemy units with assets organic to or in support of his command is called the area of influence. Furthermore there are adjacent unit boundaries which separate similar units on the ground and define left and right limits of responsibility. These are indicated by a level of command symbol (e.g., "x" for brigade). Lastly there are rear boundaries for each level of command.

4. Estimate of the Situation

Information required for planning is essential as input for the planning process. The fundamentals of defense must be kept in mind as general guidelines for defense. Organization describes the framework of how a defense should be constructed. All of these are related to a mental process which is described as the Estimate of the Situation [Ref. 4]. This estimate of the situation consists of five steps.

- Mission Analysis

- Situation and Courses of Action
- Analysis of Courses of Action
- Comparison of Courses of Action
- Decision

The first step is mission analysis. This mission is part of an Operations Order or Operations Plan which also includes the enemy forces to be engaged, and the role the receiving unit will play in the higher units' scheme of maneuver. This is like the first part of METT-T, where the received mission is broken down into specified tasks and additional tasks which are required to complete the mission. These additional or implied tasks are not stated in the mission received.

In the situation and courses of action step the defender looks at the terrain, determines avenues of approach and formations, and formulates feasible friendly courses of action to be considered. More than one course of action seems to be the rule. A course of action considers the structure of the force and a scheme of maneuver or commitment.

The next step is analysis of courses of action. This involves consideration of losses predicted, resources consumed, decision points, and general strengths and weaknesses of each course of action. In general, factors for later comparison are developed in this step. The fourth step is to use those factors in step three as a basis of comparison of the different courses of action. By comparing the various courses of action, several will be chosen as the most effective. From these selected courses of action one will be chosen as the course of action to be implemented. This selection of the best course of action represents the decision step.

B. PREVIOUS RESEARCH

In order to develop a methodology by which the planning process could be modeled it was necessary to review the actual military process and the research completed on ALARM to date. The two basic areas of research upon which most of this study is based are the Generalized Value System [Ref. 1] and the Transportation Network [Ref. 2].

The first of these areas, the Generalized Value System, provides procedures for quantifying the capability of units in terms of power and value of any object (entity) on the battlefield. Through these procedures it is possible, based upon the current situation on the battlefield, to forecast the power and the value of units or objects over time. This is accomplished through the use of various combinations of exponential functions. The ability to forecast the power and value of entities represents the departure from "current state" decision making which exists in most models the U.S. Army uses today to "future state" decision making. Since the planning process is based upon enemy and friendly capabilities the relevance of such procedures is apparent. It is also important to note the term entity applies to objects as well as units on the battlefield [Ref. 1]. This is important because it provides the planning module a common value system by which any object on the battlefield is measured. An example of this would be the power of an ammunition resupply company. Not only does the company have some inherent capability based on equipment and personnel but other units derive power from the company based on its support mission, which is providing ammunition resupply.

Another area which the study makes use of is the "Transportation Network" [Ref. 2]. This represents a departure from current terrain representation models because it does not use methods such as hex terrain or direct application of digitized terrain. In utilizing network methodologies, ALARM makes use of the extensive library of algorithms which has been developed to provide efficient techniques for determining paths and flows through networks. In addition networks provide a basis for aggregation, whether the network represents terrain or some decision methodology.

These two areas provide a basis for this study. The general scheme of ALARM can be expressed in terms of execution processes and planning processes. Execution processes refer to those modules which actually represent continuous passage of time in the combat processes. The planning processes simulate the decision making and allocation processes which are invoked based on events occurring and reported from the execution model. These modules represent the planning process from the initial deployment of forces of the corps to the termination of combat. These planning modules are broken into different planning levels. The macro planning level includes initial allocation of forces, determination of schemes of maneuver, and assignment of missions to subordinate commands. The micro level represents the decision making process which leads to the execution of previously planned actions, changes of missions to subordinate commands, etc. In general the macro level represents the overall plan, and the micro level represents adjustments necessary to insure compliance with the overall plan.

The goals of this thesis are to develop a means of generating tactical boundaries through identification of avenues of approach, and to develop a decision methodology to generate ground force missions as part of the planning model. This planning model is only one of those currently being developed. The planning model proposed represents the macro planning level. Therefore the study will deal with the decision methodologies used upon receipt of a general order to develop a plan for each level of subordinate command. This plan is based upon the information received from the execution module regarding METT-T, and follows the process described earlier as the estimate of the situation. This planning module will need to make use of subplanning modules to process the information received on friendly units and enemy units alike. The intelligence model provides information on enemy units and is currently being developed. Additional submodules which are needed, some of which have already been developed, are those pertaining to areas such as maneuver, artillery, air defense, aviation, engineer, communications, and logistics. These submodels will process much of the information and contain needed algorithms used to determine specific engagement parameters such as the best type of ammunition to use for an artillery mission. The plan determined by the proposed planning model represent when and which type of units would be needed to perform chosen missions to insure the macro plan remains feasible. This plan is multi-hour over a time horizon which is linked to the area of interest/influence of the appropriate level of command. This study will focus on the brigade and battalion macro levels of planning in terms of the scope of the problem. The additional goal of developing a method of generating avenues of approach is actually part of the macro planning process. It must be considered prior to the deployment of troops, as well as dynamically generating avenues based upon updated information of enemy capabilities through the battle.

III. AVENUE OF APPROACH GENERATION

A. INTRODUCTION

Methodology for generating avenues of approach for enemy regiments using a network representation of terrain is presented in this chapter. The methodology includes those steps needed to identify a continuous network composed of battalion routes in order to generate regimental zones of action and regimental avenues of approach. These regimental avenues of approach are needed for the next higher planning level. The zones of action are represented by boundaries forming corridors. The boundaries are the borders between which an enemy unit such as a regiment is expected to advance. They are also used as the basis of initial allocation of friendly blue units. Although red and blue units will be refered to throughout the chapter, it is assumed that the red units are attacking and the blue units are defending.

B. TERRAIN REPRESENTATION

Avenues of approach are used to indicate the routes, and zones of action represent the corridors along which enemy forces are expected to move. These corridors are linked to the size of the enemy force expected to use them. During the planning process the terrain for which a particular level of blue command is responsible is analyzed to determine the corridors that the corresponding level of red forces will use to approach probable objectives within the blue area. When considering the defensive planning process the blue plan is based on the enemy's capabilities to attack.

The terrain in the case of ALARM is modeled as an interconnected set of arcs and nodes, whose attributes describe the terrain, roads, cities, etc.. The characteristics of the arcs and nodes were enumerated and the network developed by Craig [Ref. 2] and McLaughlin [Ref. 3]. These attributes are used as inputs to the avenue of approach generation model. The detailed transportation network is used at the lowest level of planning. At higher levels of planning there is a need to aggregate the network in order to have equivalent levels of resolution for each planning level. A representation of the network in terms of arcs and nodes is shown in Figure 3.1

A portion of this network will be utilized as an example for input to the avenue of approach generation model presented later in the chapter. These characteristics of arcs and nodes are used as variables in the algorithms developed for the model. A description of the node and arc characteristics is provided in Table I.

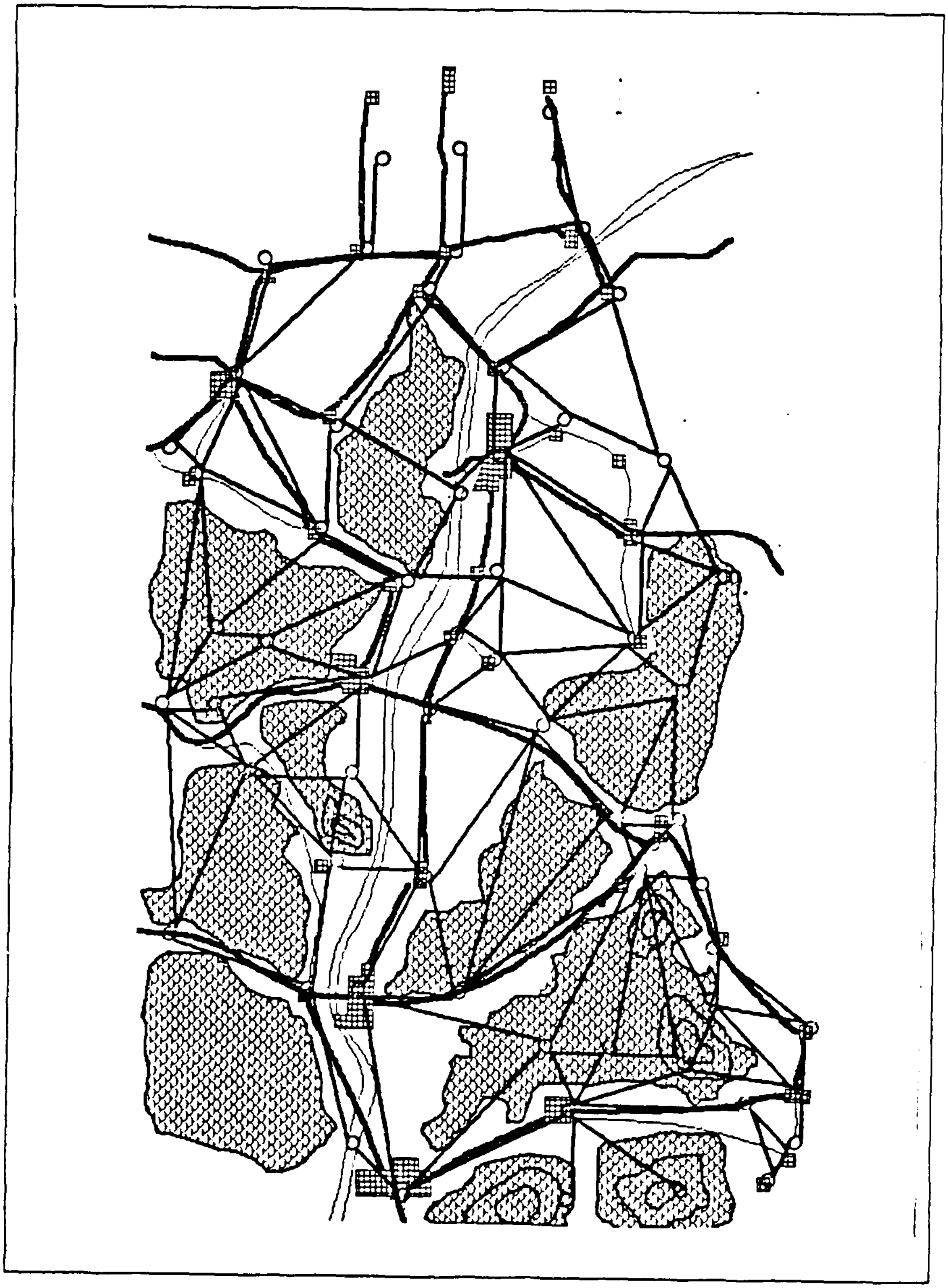

Figure 3.1 Network Representation of Terrain.

TABLE I

CHARACTERISTICS OF ARCS AND NODES

	Node Characteristics
N_i	An integer node identification number.
NV_i	A three digit latitudinal coordinate.
NH_i	A three digit longitudinal coordinate.
	Arc Characteristics
H_j	Head node identification number.
T_j	Tail node identification number.
D_j	Distance from head node to tail node.
RC_j	Integer describing route class type.
OC_j	Integer describing off route trafficability.
W_j	Width of the route represented by the arc.

Doctrinal length and width attributes are needed in order to determine avenues of approach of enemy units based on a network with characteristics such as length and width of routes, as well as trafficability along those routes. Doctrinal widths (frontages) and lengths (depths) of red units are given in Table II.

TABLE II

DOCTRINAL FRONTAGES AND DEPTHS OF SOVIET UNITS

UNIT	FRONTAGE	DEPTH
Division	10-16 Km	30-35 Km
Regiment	5-8 Km	15 Km
Battalion	1-1.5 Km	1-3 Km

Determination of regimental avenues of approach must take into consideration the frontages and depths of red regiments and battalions. In the defensive planning process the blue brigade would consider red regimental zones of action and battalion avenues of approach. These are generated through first analyzing the movement of red battalions which make up these regiments and the feasible routes on which they will advance.

C. DESIGNATION OF FEASIBLE ROUTES

Since the blue brigade plans to fight red regiments it is important to determine those arcs which are not feasible for battalions to use when advancing in the attack. To accomplish this a filtering process is used to cut these infeasible arcs from the detailed network. An example is to designate those arcs which have accessability only by dismounted troops as candidates of arcs to be eliminated. This type of criterion is used when considering the advance of red mechanized and tank forces.

In addition, those arcs which can not sustain a minimal flow rate concurrent with advancing mechanized forces are also eliminated from the input network. The following equation is used to determine flow rate of an arc and is measured in terms of battalions per hour [Ref. 6].

$$RF_j = (SP_{BN} \times W_j)/(DW_{BN} \times DD_{BN}) \qquad \text{(eqn 3.1)}$$

This equation is used for all arcs j to compute the rate of flow RF_j based on the speed of a battalion sized unit SP_{BN} multiplied by the width of the arc W_j, and that quantity divided by the product of the doctrinal width of the battalion DW_{BN} and its doctrinal depth DD_{BN}. Any arc incapable of sustaining a minimal flow rate determined by the attacking forces facing the defender is cut from the input network. The algorithm for determination of feasible routes (arcs) is as follows:

- Inputs: Network G(I,J), with I nodes, J arcs and their characteristics as described in Table I, and integer values associated with the route class RC_j and off route class OC_j describing minimal trafficability, a value for the minimal acceptable rate of flow RF_j of red battalions along an arc j, the speed SP_{BN}, doctrinal width DW_{BN} and depth DD_{BN} for the type of red battalions considered. All arcs J are initialized with a value of ID_j equal to zero.

- Outputs: A network G(I,J) containing all arcs which are feasible for sustaining advancing red battalions; these feasible arcs are indicated with an ID_j of zero, those which are not feasible have an ID_j of one.
- Step 1: Conduct a forward pass through the network; assign an indicator variable value ID_j of one to all arcs with route class equal to the input integer RC_{input}.
- Step 2: Conduct a forward pass through the network; assign ID_j of one to all arcs j with off route class greater than OC_{input}.
- Step 3: For each j calculate RF_j using equation 3.1, if the flow rate is less than the input flow rate RF_{input} then assign ID_j of one to that arc.
- Step 4: Conduct forward pass through the network for each j, if ID_j is one, eliminate that arc j from the arclist J.

Elimination of arcs in the algorithm is based on user input parameters. These parameters describe trafficability along arcs and the flow rate describes the density of movement capable over time. This process of eliminating infeasible arcs based on input parameters may indeed eliminate arcs which might be capable of limited movement. This movement would be less than desirable in most cases. However, sometimes it might be necessary to retain these less than desirable arcs. Sensitivity analysis might be useful in determining a range of input parameter values which are needed in the algorithm. This range of values would need to be sensitive to size of the unit and situation on the battlefield. This aspect is addressed as a possibility for future research in Chapter 5. For this study the designation of avenues of approach will be based on the relative measure of trafficable terrain rather than terrain less than desirable.

D. DEVELOPING A CONNECTED NETWORK

The new network created from the algorithm used to designate feasible routes can be disconnected. The use of a breadth first search algorithm is used to determine if the resulting network is connected [Ref. 7].

Connectivity is important in determination of battalion routes because any path which does not result in reaching the sink node of the network would represent a "dead end" on the actual terrain. If a disconnected network results from the determination of feasible routes algorithm it becomes necessary to cut those nodes and adjacent arcs which represent a "dead end" on the directed network. The approach which is used to determine if a network is connected is also useful for producing a connected network from one which is not. This approach determines the in-degree and out-degree of nodes within a network, and follows the guidelines used by Minieka [Ref. 7]. The in-degree represents the number of arcs going into a node. Correspondingly the out-degree represents the number of arcs leaving a node. If a node N_i exists (other than a source or sink node) such that whose in-degree ID_i is zero or its out-degree OD_i is zero, then that node represents an unconnected point in the network. This approach assumes that the network is directed. This means that there is only one direction to flow along an arc, which is from head node H_k to tail node T_k. The assumption of a directed network is linked to a red force advancing with a mission to attack. If the mission were to defend, an undirected network might be used.

Given a network which is not connected the following algorithm is used to produce a connected network of battalion paths.

- Input: A directed network G(I,K), with I nodes, and K arcs.
- Output: A connected network G(N,M).
- Initialize: $ID_i = 0$, $OD_i = 0$, for all i, $IND_k = 0$, for all k.
- Step 1: For each node N_i, other than source nodes, compare N_i with the arclist K.
- Step 2: If N_i is a tail T_k, then the in-degree $ID_i = ID_i + 1$, else $ID_i = ID_i$.
- Step 3: For each node N_i, other than sink nodes, compare N_i with the arclist K.
- Step 4: If N_i is a head node H_k, then the out-degree $OD_i = OD_i + 1$, else $OD_i = OD_i$.
- Step 5: For each node N_i, compare N_i with the arclist K.
- Step 6: If ID_i is 0 (other than source nodes) and if $N_i = H_k$ then $IND_k = 1$.
- Step 7: If OD_i is 0 (other than sink nodes) and if $N_i = T_k$ then $IND_k = 1$.
- Step 8: Conduct a forward pass through the network, if IND_k is one then eliminate arc k from the arclist K (resultant arclist has M arcs).
- Step 9: Compare N_i with new arc list M, if N_i does not exist as a tail T_m or a head H_m eliminate N_i from the network (resultant node list has N nodes).

E. ZONES ON THE NETWORK

From the previous algorithm a connected network exists through which battalion size units can advance from source node(s) through the network to sink node(s). The aggregation of battalion flow rates on routes is used to determine a corridor possessing the capability to allow the movement of a regiment. When considering the orientation from source node(s) to sink nodes(s) a network is really a series of "gates" through which battalion size units move. If a network were cut into zones perpendicular to the orientation from source to sink the measure of the flow rates across that zone represents these "gates". Indeed a zone has a number of "gates", or concentrations of flow rates equal to the number of routes through that zone and measured in rates of flow along these routes (see Figure 3.2).

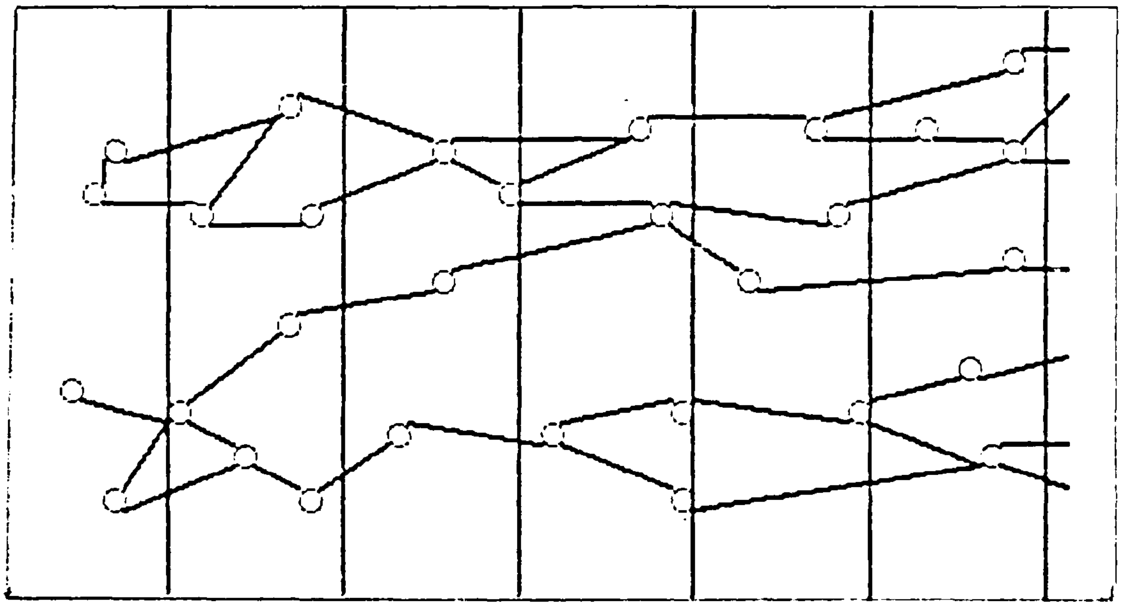

Figure 3.2 Zones on a Network.

In mixed terrain, other than completely flat (desert) or completely closed (mountains or jungle), these concentrations of flow rates create patterns. These patterns represent movement around impassable terrain, through valleys or open areas, etc. Since the connected and directed network currently depicts the lowest level of movement, these zones need to be fairly close together in order to establish the patterns or corridors of movement. In fact these zones vary dependent on the level of planning and corresponding network at which a plan needs to be made.

Since zones correspond to areas on the ground, actual grid coordinates are used to designate zone boundaries rather than an additional network to overlay on the original one. Accordingly nodes have latitudinal and longitudinal coordinates. Therefore each zone bounds the node(s) within that zone. Concentration of flow rates along routes through a zone is determined at each node in the zone. These nodes are the actual "gates". Since the flow rate going into nodes is used to determine where patterns or corridors of flow exist along a network, the nodes need to be sorted with respect to location from top to bottom perpendicular to the orientation of the network. The following algorithm is used to determine ordered node location within zones of a directed and connected network.

- Input: An array of M nodes N_m, the vertical (longitudinal) coordinate NV_m of each node m, the horizontal (latitudinal) coordinate NH_m of each node m, and a zone width distance of DZ.
- Output: A matrix $ZLIST_{ij}$, with each row i representing a zone, the elements of each row represent an ordered listing of nodes from highest to lowest node in terms of NH_m.
- Initialize: The first zone limit prior to the sink node, $c = 1, j = 0$.
- Step 1: For each node N_m determine if NV_m is greater than NV_{sink} and less than $NV_{sink} + DZ$.
- Step 2: If step 1 is true then $ZLIST_{c,j+1} = N_m$, return to step 1 until $m = M$.
- Step 3: Increment $c = c + 1$, increment vertical zone limit by DZ, initialize $j = 0$.
- Step 4: For each node N_m, if N_m is greater than $NV_{(sink)+(c-1)DZ}$ and less than $NV_{(sink)+c(DZ)}$, then add the node N_m to $ZLIST_{ij}$, otherwise check next node N_{m+1}.
- Step 5: Continue until the right most zone limit $NV_{(sink)+c(DZ)}$ includes the source node(s) NV_{source}.
- Step 6: Sort each row of $ZLIST_{ij}$ such that the N_m having the highest NV_m in each row is the first j entry, and N_m having the lowest NV_m is the last j entry in row i.

The only problem in measuring flow rates along routes at each node within a zone would be if a route traversed a zone and did not have a node in the zone to capture its corresponding flow rate in terms of battalions per hour. Therefore a "dummy" node is created on that arc in order to measure flow rate along the arc in that zone. To do this requires a pass through the network to check if any arc n consists of a head node H_n or tail node T_n having a distance of more than DZ. If such an arc exists then a node is created on that arc, located within the intermediate zone. An algorithm for determining if such arcs exist and creating a "dummy" node for each is as follows.

- Input: A network G(M,N), with M nodes, and N arcs, the characteristics of the arcs and nodes, and the ordered matrix $ZLIST_{ij}$.
- Output: A list of "dummy" nodes (if necessary), a new arclist and node list incorporating these nodes, along with their characteristics, and an updated $ZLIST_{ij}$.
- Initialize: k=0
- Step 1: For each row i of $ZLIST_{ij}$ (corresponding to the zone i), and for each node element j of that row, compare that element of $ZLIST_{ij}$ to each arc n.
- Step 2: If $ZLIST_{ij}$ equals tail node T_n, then ZT_n is equal to the zone number of T_n, else if $ZLIST_{ij}$ equals the head node H_n then ZH_n equals the zone number of H_n; continue until all matrix elements $ZLIST_{ij}$ have been checked.
- Step 3: For each arc n, compute $ZH_n - ZT_n$ and store as the zone difference between H_n and T_n for that arc; zone difference is $ZDIFF_n$; continue to compute $ZDIFF_n$ until all arcs n have been visited.
- Step 4: For each arc n, if there exists a $ZDIFF_n > 1$, then k=k+1, continue until all arcs n have been visited.
- Step 5: If k=0 then the algorithm is complete (no "dummy" nodes are necessary), else if k>0 then go to step 6.
- Step 6: For any arc n if $ZDIFF_n$ is greater than one then compare that arc n to the list of nodes M.
- Step 7: If T_n is equal to node N_m, and H_n equals a node N_l (l is a member of M), then the horizontal coordinate for each "dummy" node N_k, if $NH_m \geq NH_l$ is:

$$NH_k = \{(NH_m - NH_l)/2\} + NH_l \qquad \text{(eqn 3.2)}$$

else if $NH_l \geq NH_m$ then

$$NH_k = \{(NH_l - NH_m)/2\} + NH_m \qquad \text{(eqn 3.3)}$$

the vertical coordinate of each "dummy" node N_k, if $NV_m \geq NV_l$ is:

$$NV_k = \{(NV_l - NV_m)/2\} + NV_m \qquad \text{(eqn 3.4)}$$

else if $NV_l \geq NV_m$ then

$$NV_k = \{(NV_l - NV_m)/2\} + NV_m \qquad \text{(eqn 3.5)}$$

continue until all arcs n with $ZDIFF_n$ greater than one have been visited.

- Step 8: For each arc n, such that $ZDIFF_n$ is greater than one, then two arcs are created; the arc from H_n to N_k, and the arc from N_k to T_n; the rate of flow of the first arc is RF_n, and the rate of flow of the second arc is RF_n; the total number of arcs $N = N + k$; total number of nodes $M = M + k$.
- Step 9: Invoke the algorithm producing $ZLIST_{ij}$ to update with new arc list and node list.

F. BOUNDARIES FOR ZONES OF ACTION

Since zones of action are corridors representing the movement of a particular size of enemy unit, these corridors are be represented by creating boundaries. These boundaries are used as geometric representations of adjacent parallel limits along the route of advance of the enemy unit. Thus far the proposed avenue of approach methodology uses flow rates to create patterns that represent these corridors of advance. Zones are used to capture the flow rates to project boundaries on each zone in order to represent the parallel limits of that border (e.g., a regimental zones of action). Therefore a zone of action is represented by a series of borders in each zone as seen in Figure 3.3.

For example in developing the flow rate of a regiment, aggregation of battalion flow rates is necessary. Since a regiment is made up of battalions and a regimental artillery group, the combination of k battalions per hour is used to represent the flow rate equivalent to a regiment. Therefore an equivalence relationship is drawn to represent any hierarchy of enemy size unit through a combination of flow rates of subordinate elements. The flow rates of subordinate elements are captured at the nodes in each zone. Aggregation of flow rate concentrations at nodes are used to represent the ability of the next higher unit to move through the area.

The following algorithm is used to generate the boundaries which represent a zone of action. This algorithm uses the first row of the matrix $ZLIST_{ij}$ as the starting point.

- Input: A network G(M,N), with M nodes, N arcs, the characteristics of those arcs and nodes, a matrix $ZLIST_{ij}$ composed of I zones with J nodes (in horizontal coordinate order) in each zone, an equivalence ratio of k units per

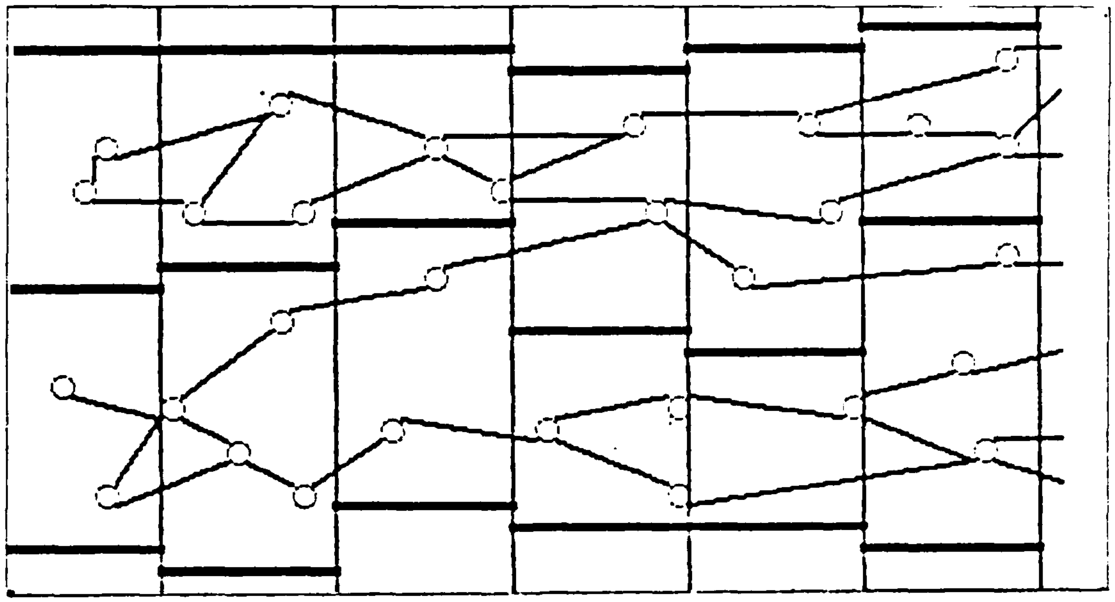

Figure 3.3 Boundaries for Zone of Action.

hour supports one unit per hour of the next higher echelon unit; the distance DZ between each zone.

- Output: A series of border coordinates for each zone i and avenue l, expressed as a vertical and horizontal coordinate for the first point in the zone, $HV1_{il}$ and $HB1_{il}$, and a vertical and horizontal coordinate for the last point in the zone, $HV2_{il}$ and $HB2_{il}$, for each boundary of a corridor l.
- Initialize: l = 1, TOTSUM = 0, $RF_{ij} = 0$, $LN_{il} = 0$, $FN_{il} = 0$ (LN and FN stand for last node horizontally in the corridor l, and first node horizontally in the corridor l + 1, respectively).
- Step 1: For each zone i, for each node in the zone j, compare $ZLIST_{ij}$ to the list of arcs N.
- Step 2: If $ZLIST_{ij}$ equals the tail node T_n then the rate of flow at that node RF_{ij} is equal to the sum of RF_{ij} and the rate of flow RF_n; continue until all elements of $ZLIST_{ij}$ are visited.
- Step 3: For each i, and for each j in $ZLIST_{ij}$; if the sum

$$TOTSUM_{il} = TOTSUM_{il} + RF_{ij} \qquad \text{(eqn 3.6)}$$

is greater than k units per hour, then LN_{il} is equal to $ZLIST_{ij}$ and $FN_{i,l+1}$ is equal to $ZLIST_{i,j+1}$, for each zone i; continue until i = I, and increment l = l + 1.

- Step 4: For each zone i, and for each corridor l, compare LN_{il} and FN_{il} to the list of nodes M.
- Step 5: Find the associated NV_m and NH_m for LN_{il} and FN_{il} then

$$HB1_{il} = \{[NH_{LN_{il}} - NH_{FN_{il}}]/2\} + NH_{FN_{il}} \quad \text{(eqn 3.7)}$$

$$VB1_{il} = NV_{sink} + (l-1)DZ \quad \text{(eqn 3.8)}$$

$$VB2_{il} = NV_{sink} + (l)DZ \quad \text{(eqn 3.9)}$$

$$HB2_{il} = HB1_{il} \quad \text{(eqn 3.10)}$$

continue for each zone i, and each avenue l.

The previous steps of the avenue of approach methodology can be applied for any situation which occurs on the terrain network. The methodology of generating boundaries for zones of action is a heuristic, and although reasonable results are generated, deficiencies exist. Even though this algorithm is an initial attempt at generating zones of action within ALARM, it yields relative rather than absolute results. Certain anomalies could exist within the terrain network which are not accommodated by the algorithm. Network configurations could arise in which a zone is bordered by boundaries which either cut across lateral access routes or do not provide a route to the next zone. This situation could be the result of the measure of flow within the zone. These situations need to be explored further and will be referred to in Chapter 5.

G. AGGREGATION OF ARCS AND NODES

The methodology to produce regimental avenues of approach provides the framework to aggregate those nodes and arcs within the zone of action into a series of arcs representing regimental arcs and nodes. This is important because it will represent the network required for the next higher level of blue command to use in the planning process. Since each corridor represents the area necessary for a regiment to move, a single path is generated to represent the flow of a single regiment. The node with the greatest flow rate into it in each zone of the corridor represents the point of concentrated flow in that zone. It is also necessary to retain the total flow rate through a zone in the case when many routes with small amounts of flow across them occur within a zone. In addition the in-degree of that node retained is useful at higher levels in consideration of engineer obstacle placement priority. It is noted here that the path generated may not necessarily appear linear across a corridor, due to the terrain that the corridor represents (see Figure 3.4).

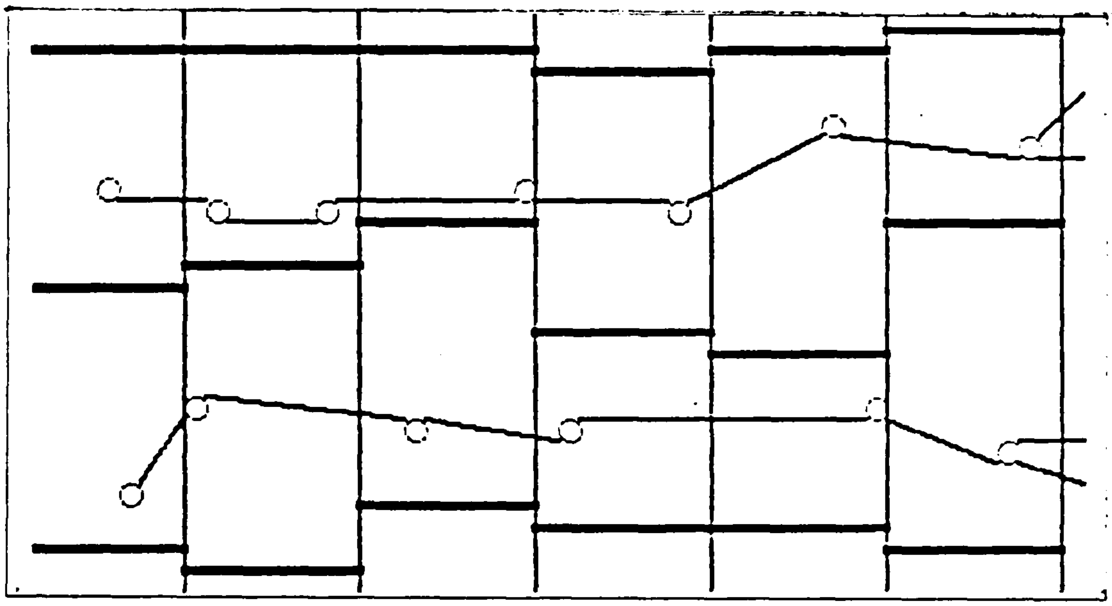

Figure 3.4 Regimental Paths Generated Through Aggregation.

In order to generate the set of arcs and nodes representing the regimental path, avenue of approach, the following algorithm is used.

- Input: A network G(M,N), with M nodes, N arcs and their characteristics; $ZLIST_{ij}$, the matrix of rates of flow RF_{ij}; the total sum of flow rate in each zone i and corridor l $TOTSUM_{il}$; the $HB1_{il}$, $HB2_{il}$, $VB1_{il}$, and $VB2_{il}$ for each zone i and corridor l.
- Output: A list of arcs and nodes for each regimental avenue of approach.
- Initialize: $x = 0$, $k = 0$

- Step 1: For each zone i, for each node element j of $ZLIST_{ij}$, in corridor l, compare $ZLIST_{ij}$ to the list of nodes M.
- Step 2: If the NH_m and NV_m associated with $ZLIST_{ij}$ are between the lower vertical boundary ($VB1_{il}$,$HB1_{il}$ to $VB2_{il}$,$HB2_{il}$)and the upper vertical boundary ($VB1_{i,l-1}$,$HB1_{i,l-1}$ to $VB2_{i,l-1}$,$HB2_{i,l-1}$) of avenue l, then go to next step; else go to the next zone in corridor l.
- Step 3: If the $RF_{ij} > x$ then the regimental node $RN_{il} = ZLIST_{ij}$, the regimental rate of flow $RRF_{il} = TOTSUM_{il}$, and x is now equal to RF_{ij}; if $RF_{ij} < x$ then continue to the next $ZLIST_{ij}$.
- Step 4: For each i, for each l, compare RN_{il} to the arclist N.
- Step 5: If RN_{il} is equal to the tail node T_n, then the number of arcs into the regimental node $NAR_{il} = k+1$, return to step 4 until i=I, and l=L.

In summary a methodology has been proposed for generating avenues of approach of enemy units, regiments, utilizing as input a network representing terrain. This has been accomplished through a series of algorithms which:

- Eliminate arcs (routes) which are not capable of sustaining the movement of advancing red battalions.
- Develop a connected network after those infeasible arcs are eliminated.
- Generate zones on the network by which concentrations of flow rate are used to determine zones of action, corridors, of advancing red regiments.
- Generate "dummy" nodes to represent the flow of routes crossing zones where previously the flow rate could not be measured.
- Generate boundaries as a representation of the zones of action.
- Generate regimental avenues of approach as a series of arcs and nodes through the corridors.

In order to demonstrate this methodology, the following section presents an example using a portion of the terrain network in ALARM.

H. AN EXAMPLE OF AVENUE OF APPROACH GENERATION

This section primarily deals with demonstration of the methodology proposed thus far, through an example. The example will utilize a portion of the terrain network used in ALARM [Ref. 2]. This terrain represents a part of the U.S. Army's V Corps area just east of Bad Hersfeld, Federal Republic of Germany. The scenario for the example represents that part of a blue brigade defensive planning process which is concerned with designating avenues of approach of red motorized rifle regiments (MRR). Specifically this example will produce:

- A zone of action of one red MRR.

- The regimental avenue of approach associated with the path of arcs and nodes.

This will be accomplished by looking at an area which is capable of sustaining a red motorized rifle division (MRD). The area represented by the network is approximately twenty kilometers in width by twenty-five kilometers in depth. The actual network used to represent this area contains 127 arcs and 62 nodes (see Appendix A). Along with the arcs and nodes, the corresponding characteristics used are those as listed in Table 3.2. The network is shown in Figure 3.5.

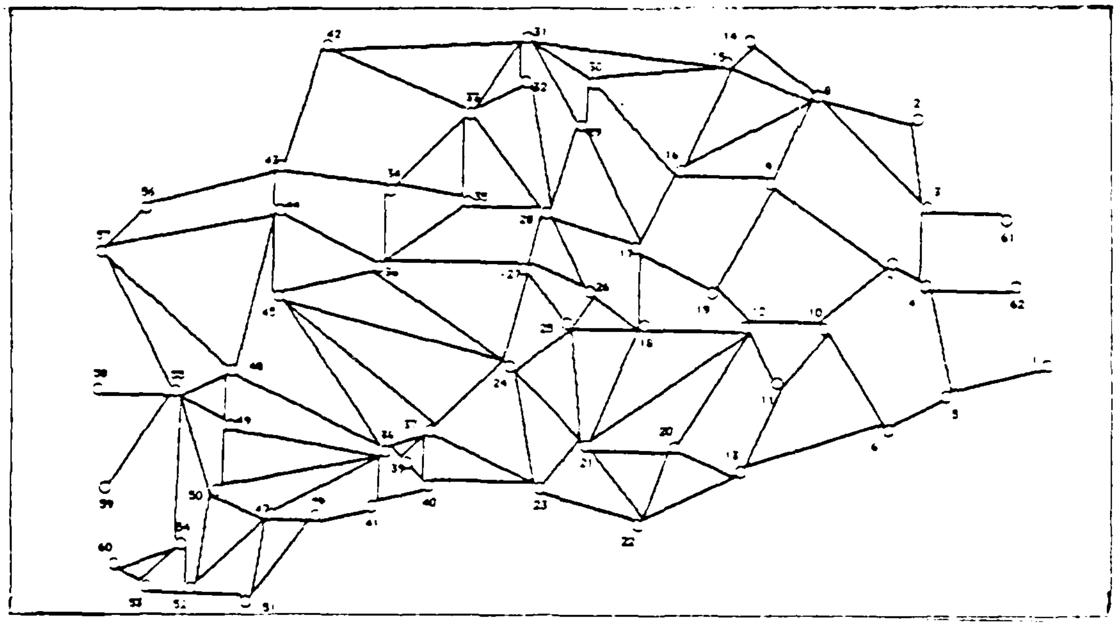

Figure 3.5 Example Network.

The first step in the generation of avenues of approach is to cut those arcs from the network which are incapable of sustaining an advancing red battalion size unit. For the example a route class RC_j of seven indicating forested terrain will not sustain the movement of a motorized rifle battalion. In addition any arc with a capability of sustaining a rate of flow RF_j of less than .5 battalions per hour is also considered as an infeasible route for advance. The speed of a red motorized rifle battalion SP_{BN} across mixed terrain is five kilometers per hour [Ref. 4]. The doctrinal depth of a red motorized rifle battalion DD_{BN} is three kilometers, and the doctrinal width DW_{BN} of the battalion is one kilometer (see Table II). These factors, along with the network, are used as inputs to the algorithm for designating feasible routes (see Appendix B). This algorithm produces a new network excluding infeasible arcs. A representation of the resulting network appears in Figure 3.6.

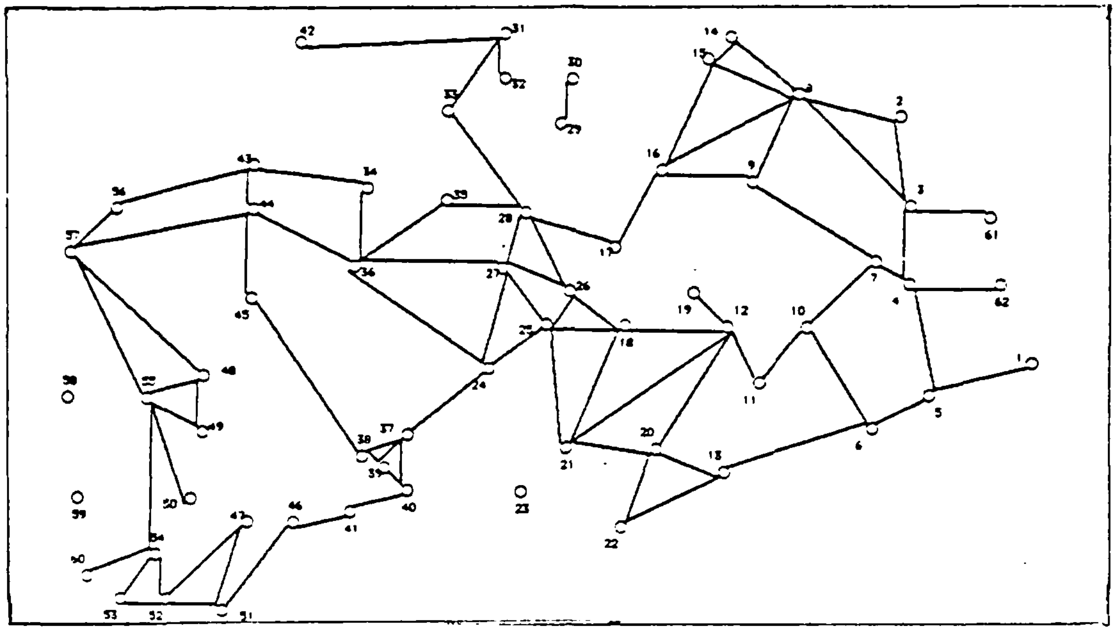

Figure 3.6 Network of Feasible Battalion Arcs.

The next step in the avenue of approach generation model is to generate a connected network using the network of feasible routes (arcs) as input. Those nodes N_i and adjacent arcs, $N_i = H_j$ (other than source nodes) having in-degree ID_i equal to zero are cut from the network. Likewise those nodes N_i and adjacent arcs $N_i = T_j$ (other than sink nodes) having out-degree OD_i equal to zero are cut from the network. The resulting acyclic connected network generated using the algorithm for developing a connected network is shown in Figure 3.7.

The methodology to this point has produced a network composed of arcs capable of sustaining advancing red battalions. In addition any series of arcs starting from the source nodes is capable of supporting movement through the network to the sink nodes (i.e. an acyclic, connected, and directed network exists). As described earlier in this chapter the ability of regimental size units to move through an area is modeled by designating concentrations of battalion flow rates by means of zones. These zones form a continuous series of sections across a network. By measuring the rates of flow into nodes located within each zone, patterns of flow exist. These patterns represent actual corridors around hindering terrain through which units such as regiments would be likely to move in the attack. For this example zones are designated every two kilometers, starting at the sink nodes, moving backwards through the network until the

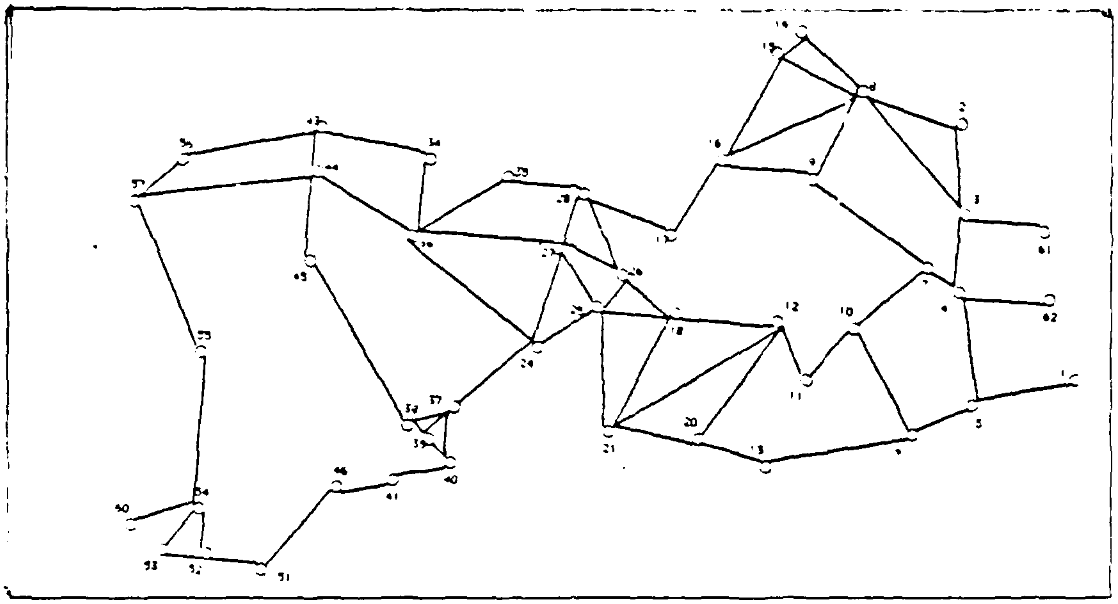

Figure 3.7 Connected Network of Battalion Arcs.

last zone includes the source nodes. The nodes N_m are grouped into each zone i according to the latitudinal coordinate NH_m (see Figure 3.8).

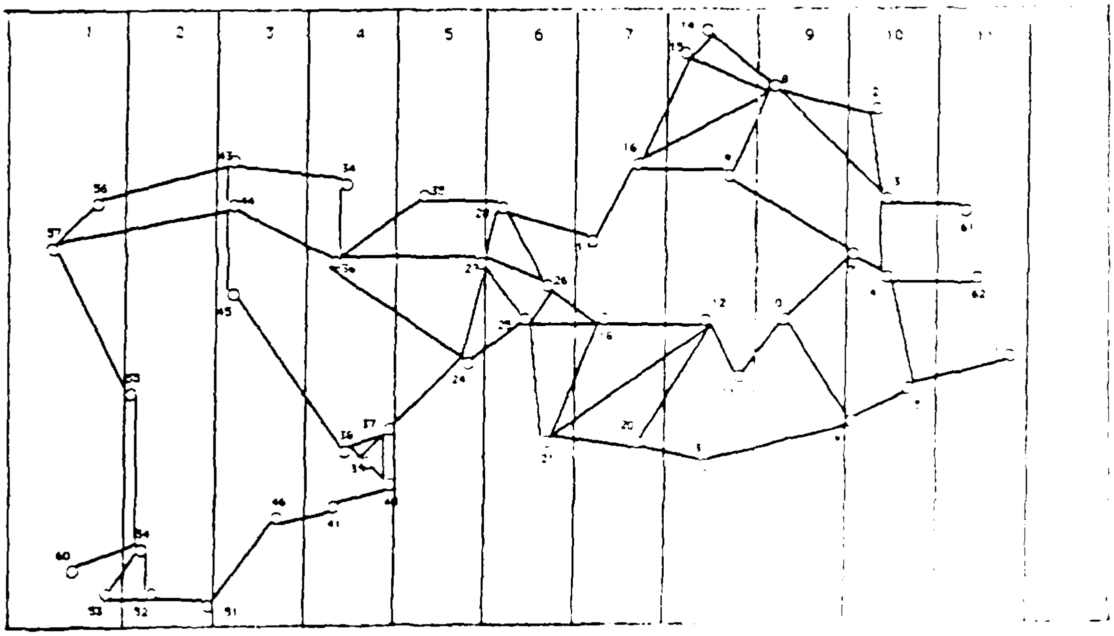

Figure 3.8 Zones of the Network of Battalion Arcs

These zones contain all the nodes of the network. The algorithm discussed earlier in this chapter is used to generate the zones based on an input distance between each zone i of DZ=2 (see Appendix B for program). In generating the zones the algorithm is able to determine a matrix $ZLIST_{ij}$ which represents the ordered list of nodes from sink nodes to the source nodes. Each row i is based on the longitudinal coordinate NV_m of each node N_m and ordered on the latitudinal coordinate of the node NH_m This ordering is from uppermost to lowest node perpendicular to the orientation of the network (see Table III).

TABLE III

MATRIX OF ZONE ORDERING OF NODES

ZONES										
1	2	3	4	5	6	7	8	9	10	11
56	55	43	34	35	28	16	14	8	2	61
57	54	44	36	27	26	17	15	10	3	62
60	52	45	37	24	25	18	9		7	1
53	51	46	38		21	20	12		4	
			39				11		5	
			40				13		6	
			41							

This grouping of nodes is used to determine concentrations of flow rates, which through aggregation represent regimental movement through this area. Using flow rates to measure the ability of red battalions to move along arcs requires nodes into which flow rates can be aggregated. Upon inspection of the network there are several arcs n, passing through zones in which neither a head node H_n or a tail node T_n to the arc resides in the zone. The algorithm for generating "dummy" nodes is used to add nodes N_k to the network, in order to aggregate the flow rate of those arcs n so indicated (see Appendix C). The resultant network with the addition of these "dummy" nodes is shown in Figure 3.9.

This algorithm makes appropriate changes and additions to the arclist N+k. The matrix of ordered nodes j per zone i, $ZLIST_{ij}$, will also be updated (see Table IV).

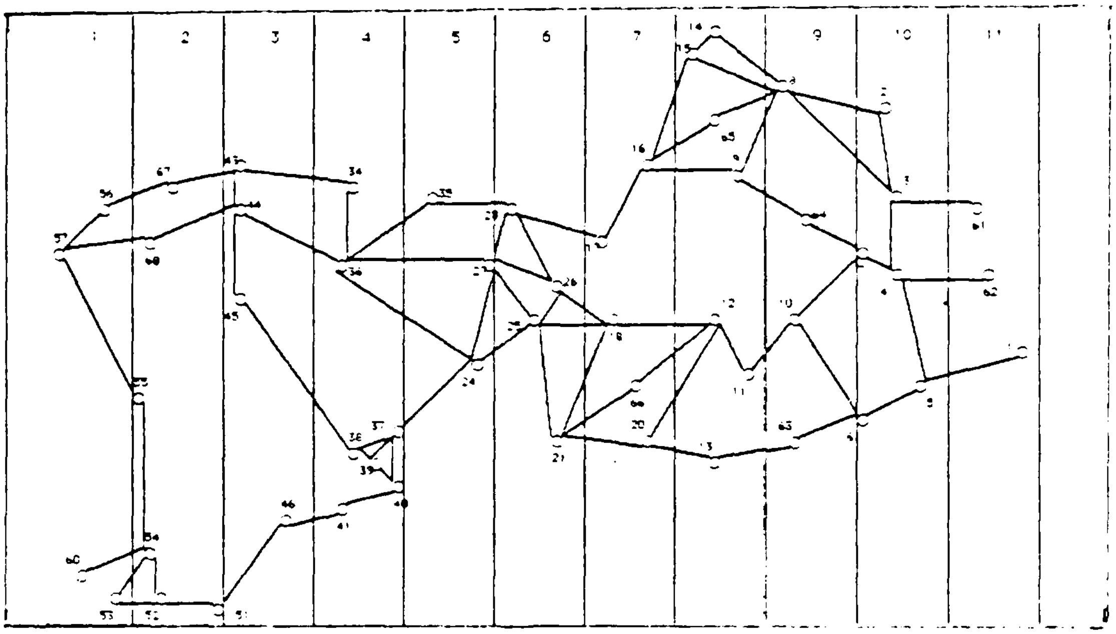

Figure 3.9 Network With New "Dummy" Nodes Added.

TABLE IV

UPDATED MATRIX OF ZONE ORDERED NODES

ZONES

1	2	3	4	5	6	7	8	9	10	11
56	67	43	34	35	28	16	14	8	2	61
57	68	44	36	27	26	17	15	64	3	62
60	55	45	37	24	25	18	65	10	7	1
53	54	46	38		21	66	9	63	4	
	52		39			20	12		5	
	51		40				11		6	
			41				13			

Those nodes k, numbered 63 through 68, are the "dummy" nodes which have been generated. A detailed list of the new network in terms of an updated list of nodes m, arcs n, and their new characteristics is provided in Appendix C.

Having generated a new ordered matrix $ZLIST_{ij}$, boundaries are formulated which represent the corridor through which a red MRR will flow. To demonstrate this, the algorithm for generating boundaries for zones of action is used (see Appendix B). The inputs to this algorithm are the updated matrix of ordered nodes $ZLIST_{ij}$, the connected network G(M,N), the distance of DZ = 2 kilometers between each zone, and an equivalence ratio of five battalions per hour used to represent the flow of one red MRR. The equivalence of five battalions per hour is used to represent the flow of one MRR because the regiment is composed of four maneuver battalions and one artillery battalion. This is only one possible equivalence relationship which could be used. Also the normal depth of the regiment is approximately five kilometers, with a speed of about five kilometers per hour. Therefore the equivalence of five battalions per hour to one regiment per hour is reasonable. Since zone of action boundaries are generated based on battalion flow rates, Table V represents the battalions per hour flow rates which are measured in terms of flow into the nodes N_m listed in Table IV that accompany $ZLIST_{ij}$.

TABLE V

BATTALION FLOW RATES INTO NODES OF ORDERED ZONE MATRIX

ZONES

1	2	3	4	5	6	7	8	9	10	11
1.67	1.67	.83	1.67	1.67	2.50	4.17	.83	4.17	1.67	.00
4.17	1.67	3.33	4.16	3.34	1.67	.83	1.66	1.67	3.34	.00
1.67	1.67	.83	.83	3.34	4.17	1.67	1.67	3.34	1.67	.00
.83	3.34	1.33	1.67		5.01	1.67	3.34	1.67	3.34	
	1.67		1.67			3.34	1.67		1.67	
	1.67		2.50				1.67		1.67	
			1.67				1.67			

The algorithm for generating boundaries cuts the matrix in each column when the node added to each zone partition equals or exceeds the equivalence ratio value of five battalions per hour the first time. This represents the lower boundary of the first corridor in each zone (see Figure 3.10).

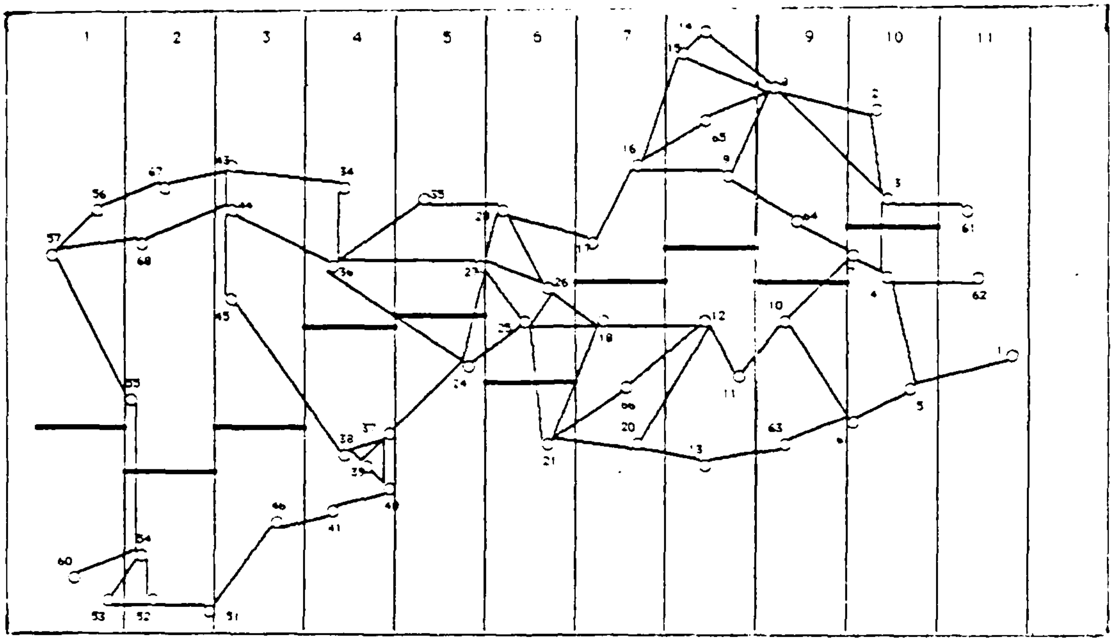

Figure 3.10 The Boundary of The First Regimental Zone of Action.

For the purpose of the example, only the first regimental zone of action boundary was generated. The following vertical boundary coordinates ($VB1_{i1}$,$VB2_{i1}$) and horizontal boundary coordinates ($HB1_{i1}$,$HB2_{i1}$) are the actual points which mark the corridor in each zone (see Table VI).

TABLE VI

VERTICAL AND HORIZONTAL BOUNDARY COORDINATES

Zone	($VB1_{i1}$,$HB1_{i1}$)	($VB2_{i1}$,$HB2_{i1}$)
1	720 278	740 278
2	740 267	760 267
3	760 277	780 277
4	780 295	800 295
5	800 302	820 302
6	820 286	840 286
7	840 311	860 311
8	860 317	880 317
9	880 312	900 312
10	900 321	920 321

The corridor represented by the boundaries in each zone is that area along the orientation of the network able to sustain the movement of a red MRR. In order to aggregate the battalion arcs and nodes in this region into a path of arcs and nodes for a regiment, the algorithm for generation of a regimental path is used (see Appendix B). Those nodes N_m having the greatest flow rate into them will be retained as regimental nodes in that avenue of approach RN_{il}. Along with these regimental nodes, a list of regimental arcs is generated for the avenue. The actual regimental path is shown in Figure 3.11.

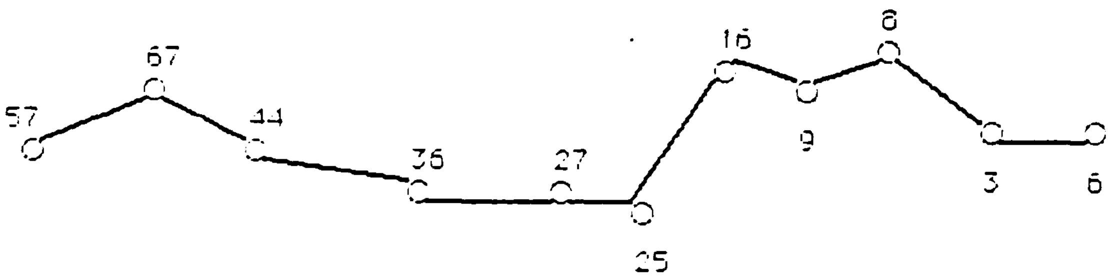

Figure 3.11 Regimental Arcs and Nodes of the First Avenue.

The total sum of the flow rate $TOTSUM_{il}$, the number of arcs into that node ID_m, the horizontal and vertical coordinates of the node NH_m and NV_m, and the actual flow rate into that node RF_{il} are returned by the algorithm for information needed at the next higher planning level.

This example has demonstrated the use of avenue of approach generation. Specifically the example has shown how the zone of action of one MRR is designated, along with the associated regimental avenue of approach. Once all regimental zones of action and avenues of approach are generated within a network, these are used as a basis for allocation of units and designation of sectors for those units belonging to the blue brigade.

Although this example deals with a blue brigade and red regiments, regimental avenues and paths are used as input to the planning process at the division and corps levels. The avenues generated are used in the unit allocation process in the development of the macro plan for each hierarchical level. From this macro planning process a series of missions for subordinate levels are developed. Once a subordinate unit receives the mission it must go through a planning process to develop a macro plan. Upon receipt of a mission this macro plan generation is concerned with actual asset to target combinations over time in order to sustain the thresholds associated with that mission. Macro plan generation is the topic of the next chapter.

IV. THE PLANNING MODEL

A. INTRODUCTION

This chapter sets forth the methodology for a planning model, that represents the defensive planning process which, upon receipt of an order from the next higher level of command, develops a plan over a time horizon for subordinate units. This plan is a series of times and missions for subordinate units to be committed in order that the higher level plan can be achieved. The plan that is developed is called the macro plan. The development of a macro plan assumes that part of the macro plan received includes a sector for the receiving command level. The development of the defensive plan also assumes some degree of knowledge of enemy capabilities. In fact the elements of METT-T discussed in Chapter 2 will be factors used as inputs to the planning model. The sector of responsibility is an extention to avenue of approach generation. Factors of METT-T are received as input from current models incorporated in ALARM presently or those being developed as part of the research process. The key factor of the planning model will be the ability to produce a plan which projects power of friendly and enemy units in future time based on current information. The basis for this determination of power was proposed by Kilmer [Ref. 4], and embodies the constructs of the generalized value system (GVS). The GVS is a means by which the power of units (entities) can be measured over time in relation to when those units are able to accomplish missions. The use of GVS in the defensive plan generation process will be discussed in detail in the next section.

In order to explore the methodology used in developing a planning model, a modification of the estimate of the situation process described in Chapter 2 will be used as the model counterpart. Prior to this, however, a discussion of how power will be measured is necessary.

B. MEASURING POWER

Kilmer [Ref. 1] proposed that there are two types of power; inherent and derived. The total power of a entity, or unit, is the sum of its inherent and derived power. The power of entities is measured in terms of STAPOWS (standard power). Certain entities may have only inherent power or derived power, while others may have both. Inherent power is the ability to disrupt, delay or destroy the enemy and can be thought of as combat power. Derived power of an entity results from the ability of that entity to change or maintain the inherent power of other entities. An example of an entity that will have inherent power is a combat unit, such as an infantry battalion or tank regiment. On the other hand, entities such as bridges, intelligence units, command and control headquarters, or ammunition supply units have derived power.

In the GVS, inherent power is broken into several elements. Basic inherent power (BIP) is the inherent power possessed by an entity at full strength when it is in position to accomplish a mission against its most likely adversary. The determination of the position at which an entity achieves maximum power will be computed for each specific situation. The adjusted basic inherent power (ABIP) of an entity is the BIP of the entity adjusted for the mission and condition of the entity. The situational inherent power (SIP) of an entity is the inherent power that entity is predicted to have at some time t. The assumption here is that power increases exponentially over time withour attrition the closer an entity comes to performing its mission. Therefore by relating these measures of power to some entity i whose expected position to accomplish a mission is known, the inherent power of the entity before, during, and after the time the entity expects to arrive at that position is determined.

The time of arrival $t_{a,i}$ of entity i is currently calculated by using the distance $DIST_i$ the entity is from that position and the speed $SPEED_i$ at which the entity is able to move over the transportation network to that position, hence t_a equals $DIST_i/SPEED_i$. These would be inputs to the model based upon information accessed from the terrain network, along the minimum time path.

Knowing the BIP_i of entity i, the $ABIP_i$ of the entity is determined by discounting back to the present time. The $ABIP_i$ is a function of the BIP_i, the distance from the postion where the unit is to accomplish its mission $DIST_i$, the condition of the unit $STATE_i$, and a factor $K_{i,m}$ associated with the mission assigned. $STATE_i$ includes that percentage of equipment, personnel and ammunition that an entity i possesses at the present time t_p. $K_{i,m}$ is an input factor by the user that when multiplied by the BIP_i yields an updated BIP_i based on the mission of i against an adversary. The function of the $STATE_i$ results in one for each entity ($0 \leq STATE_i \leq 1$). The $f(STATE_i)$ used later in the example is the square root of the product of percentages of equipment, and personnel on hand. This is one function that can be used to describe the readiness state of a unit. $ABIP_i$ is a measure of the power of entity i at the beginning of the planning time period when $t_p < t_{a,i}$. The equation for computing $ABIP_i$ is:

$$ABIP_i = BIP_i \times (K_{i,m}/DIST_i) \times f(STATE_i) \qquad \text{(eqn 4.1)}$$

Now assuming that power increases exponentially the closer a unit comes to performing a mission, the $SIP_{i,t}$ for $t < t_{a,i}$ can be computed.

$$SIP_{i,t} = ABIP_i \exp(B_i \times t) \qquad \text{(eqn 4.2)}$$

The exponent B_i is the rate at which the power increases over time from t_p to $t_{a,i}$. It was computed using the following equation.

$$B_i = \{\ln(BIP_i/ABIP_i)\}/t_{a,i} \qquad \text{(eqn 4.3)}$$

After an entity is at its position for accomplishment of mission, the SIP_i can be calculated assuming that the power of the entity will decay exponentially over time. The entity will consume resources at some usage rate $U_{i,m}$ based upon its mission m, or engage an enemy entity j with some attrition rate $ATT_{i,j}$. In many cases the usage rate $U_{i,m}$ will be significantly less than the attrition rate due to enemy fires $ATT_{i,j}$. Therefore the $SIP_{i,t}$ for $t > t_{a,i}$ would take the following form if entity i has not yet engaged the enemy.

$$SIP_{i,t} = SIP_{i,t_{a,i}} \exp(-U_{i,m} \times (t - t_{a,i})) \qquad \text{(eqn 4.4)}$$

If the entity i has engaged the enemy then the following equation is used.

$$SIP_{i,t} = SIP_{i,t_{a,j}} \exp(-ATT_{i,j} \times (t - t_{a,j})) \qquad \text{(eqn 4.5)}$$

It is noted here that attrition can occur prior to time of arrival $t_{a,j}$. This situation along with multiple attrition due to engagement by several units will be discussed later in the chapter. A combination of these equations used in measuring power of an entity over time is represented graphically in Figure 4.1.

Through the use of these equations the inherent power of any entity on the battlefield considered in the time horizon is determined for the defensive planning process.

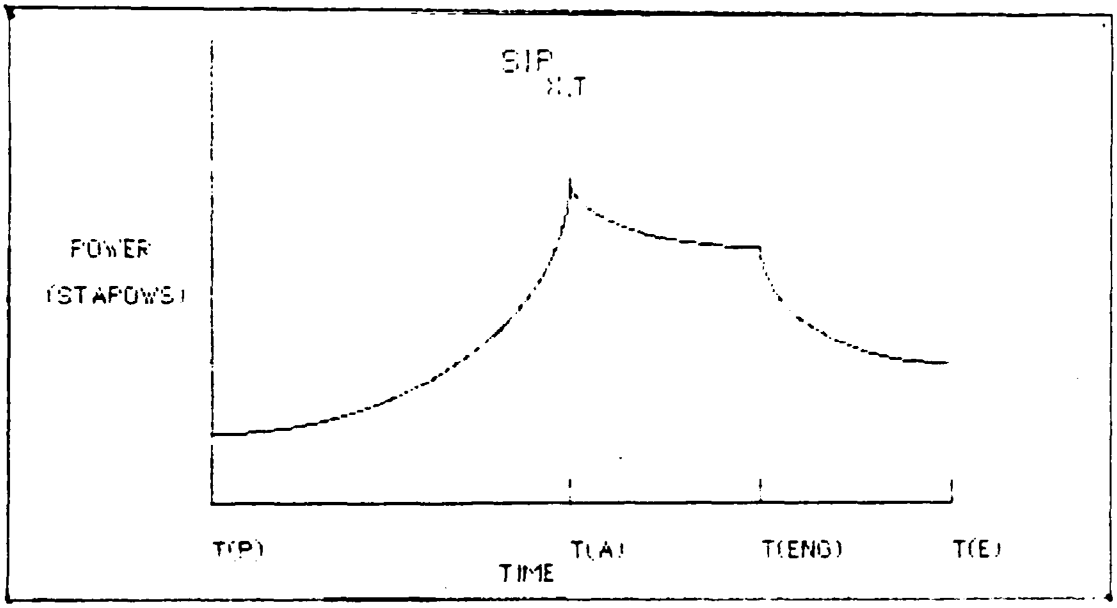

Figure 4.1 Power of an Entity Over Time.

C. THE PLANNING PROCESS

The defensive planning process begins with the receipt of an order from the next higher command level. This order is part of the macro plan. The mission is a series of input parameters which describes the situation on the battlefield as it exists at the present time t_p. After receipt of the order, a modified estimate of the situation is used to describe the process utilized in the planning model. This modified estimate of the situation is as follows:

- Determination of initial mission feasibility.
- Designation of decision point.
- Developing feasible courses of action.
- Selection of a course of action to restore feasibility.

This modified process represents the modeling of the real world estimation process. Through the use of those equations based on the GVS it is possible to computationally predict plan feasibility based on red force versus blue force power comparisons within a sector, whether a plan will be able to accomplish the mission received from higher command levels, and what assets need to be used at some time in order to assure the mission is accomplished.

D. INITIAL MISSION FEASIBILITY DETERMINATION

Initial mission feasibility concerns whether or not a threshold interval of the difference in power is maintained throughout the decision period, with an initial commitment of friendly forces to the FEBA battle. Once a mission has been received, along with a friendly troop list, the model developed by McLaughlin [Ref. 3] for positioning of forces in the assigned sector determines the forces necessary to fight the FEBA battle. In addition it indicates the positions on the network where those forces will defend. At this point it is also assumed that the intelligence model, currently under development, will be able to provide the necessary inputs pertaining to enemy force attack scenario in so far as an order of battle and current position of forces is concerned. With this information it is possible to compare the power of both red and blue forces within a sector. The decision period relates to the area of interest, as described in chapter 2, but can also be extended to any length of time. The present time t_p will be the start point for the decision period.

Determination of feasibility of the initial mission is based on the comparison of blue force power and red force power. For purposes of simplification each force's power is computed to be the sum of the power of subordinate units or entities within each force. The force is defined as those units within a sector that have an assigned mission within that sector. Therefore over a decision period from t_p to the end of the decision period, t_e, summing over all entities of each force in terms of the respective $SIP_{i,t}$ for each entity results in a total $SIP_{x,t}$ for the blue force, and $SIP_{y,t}$ for the red force. The equations used for comparison of power within a sector for blue forces x_i and red forces y_j are as follows:

$$SIP_{x,t} = \sum_i ABIP_i \exp(B_i \times t) \qquad (i = 1,\ldots,I) \qquad \text{(eqn 4.6)}$$

$$SIP_{y,t} = \sum_j ABIP_j \exp(B_j \times t) \qquad (j = 1,\ldots,J) \qquad \text{(eqn 4.7)}$$

These are the sum of the power for each force for $t_p \le t \le t_{a,i}(t_{a,j})$. Here $t_{a,i}(t_{a,j})$ is the time of arrival to accomplish a mission for the units designated for the FEBA battle. Additionally each asset i_{nc} not committed to the FEBA battle will be assumed to have a $t_{a,i}$ associated with its most likely mission m. For example an artillery battalion in direct support of a brigade would move to a position where it could fire in support of the brigade. After the forces reach there respective positions the following equations are used to determine power within the sector.

$$SIP_{x,t} = \sum_{i\varepsilon\{I_{nc}\}} \{SIP_{i,t_{a,i}} \exp(-ATT_{i,j} \times (t-t_{a,i}))\} \qquad \text{(eqn 4.8)}$$

$$+ \sum_{i_{nc}} \{SIP_{i,t_{a,i}} \exp(-U_{i,m} \times (t-t_{a,i}))\} \qquad (i=1,...,I)$$

$$SIP_{y,t} = \sum_{j\varepsilon\{J_{nc}\}} \{SIP_{j,t_{a,j}} \exp(-ATT_{j,i} \times (t-t_{a,j}))\} \qquad \text{(eqn 4.9)}$$

$$+ \sum_{j_{nc}} \{SIP_{j,t_{a,j}} \exp(-U_{j,m} \times (t-t_{a,j}))\} \qquad (j=1,...,J)$$

These equations are for $t_{a,i} \leq t \leq t_e$ and $t_{a,j} \leq t \leq t_e$. For the comparison of the power difference in sector the following equation is used for $t_p \leq t \leq t_e$.

$$DIFF_t = SIP_{y,t} - SIP_{x,t} \qquad \text{(eqn 4.10)}$$

The limits or thresholds of power difference are mission linked. The upper threshold T_u, represents a red force power too large for committed forces to defend against. Additionally a lower threshold T_l, represents a difference that suggests an over commitment of friendly forces. Graphically the comparison of blue and red force power curves and the associated difference curve illustrating the use of thresholds is shown in Figure 4.2, and 4.3.

If the difference between the power curves violate the upper threshold value, the initial macro plan is considered infeasible in terms of friendly force commitment. Violation of the lower threshold value indicates the possibility of recommitment of forces elsewhere or possibly the opportunity to attack by blue forces. This study will concentrate on the violation of the upper threshold limit to determine feasibility of the initial plan.

The methodology for determining $SIP_{i,t}$ based on considering the power of uncommitted units as though they were committed to their most likely mission is the basis for determination of feasibility throughout the decision period from t_p to t_e. Assuming discrete time intervals Δt, if these originally uncommitted forces' power are time stepped throughout the remainder of the decision period, it indicates when these

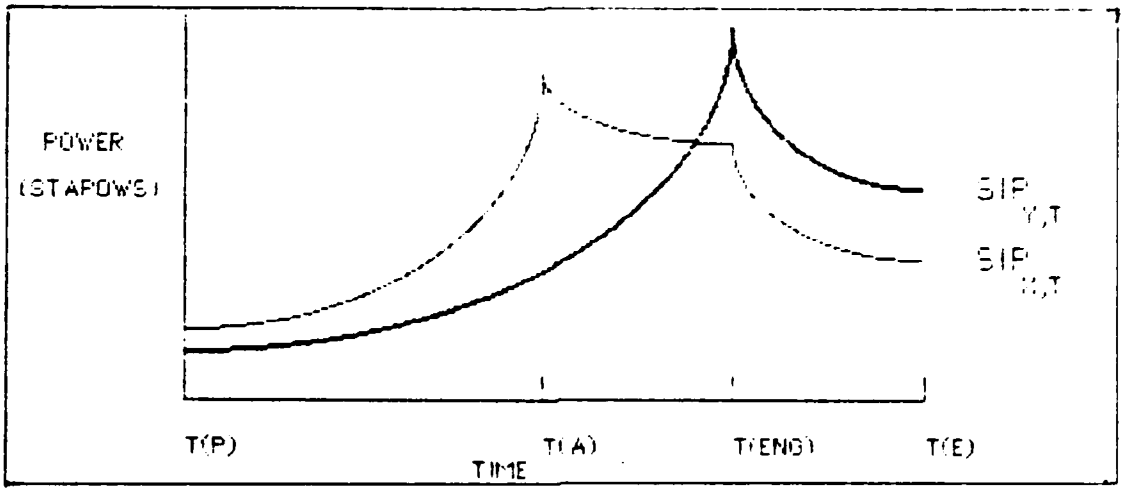

Figure 4.2 Red and Blue Power Curve Comparison.

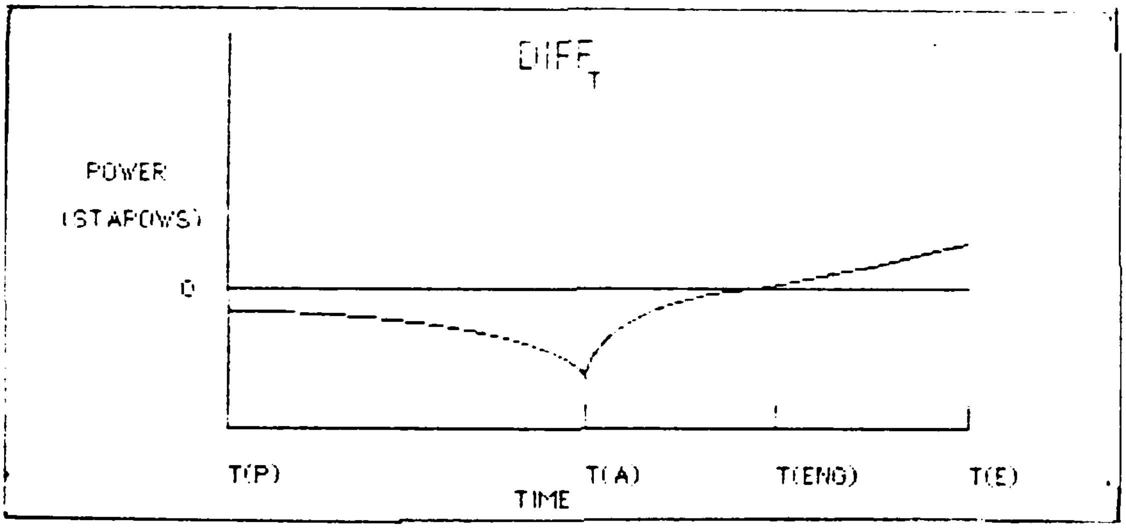

Figure 4.3 Resulting Difference Curve.

forces need to be committed. The time of commitment is related to the violation of the upper threshold value. The concept is to time step through the decision period, counting the contribution of these uncommitted forces' power later in the comparison process. If time stepping throughout the decision period without counting the contribution of these originally uncommitted forces did not cause a violation of the threshold, then only the originally committed FEBA forces are needed to maintain the power differential in that sector. If, through discrete time stepping, a point of infeasibility occurs, then this indicates a point in time at or before forces needed to be committed in order to maintain a difference below the threshold value. This time is referred to as the decision point.

An algorithm for determining feasibility is as follows:

- Start at the present time t_p, generate all $SIP_{i,t}$ for each x_i, committed and noncommitted units $(i = 1,...,I)$.
- Compute $SIP_{x,t}$.
- Generate $SIP_{j,t}$ for each y_j $(j = 1,...,J)$.
- Compute $SIP_{y,t}$.
- Compute $DIFF_t$.
- If $DIFF_t > T_u$ then associated $t = t_d$.
- Increment t_p by Δt, generate all $SIP_{i,t}$ for each i_{nc}, x_i not committed, with start time $t_p = t_p + \Delta t$, for $t < t_p$, i_{nc} will have $SIP_{i,t} = ABIP_i$.
- Return to start, if t_p for $i_{nc} < t_e$.

E. DESIGNATION OF THE DECISION POINT

A decision is required at the point in time where the value of the difference curve exceeds the upper threshold value, based on the comparison of red and blue force power functions. The decision point is used as a basis for determining when the blue forces need to have affected the power of the red forces predicted against them. This assumes the red force plan remains constant throughout the planning process. Therefore the methodology develops a plan based upon the most recent red plan of battle using intelligence prior to the time t_p, at which the planning model is invoked.

The decision point provides that time on or before which the blue force must make some asset allocation in order to decrease red power, delay it, or a combination of both. The decision point also indicates the magnitude of the power measured in STAPOWS of the amount of red power which needs to be decreased in order to maintain feasibility. Thus the blue force has a time period, from t_p to the decision point t_d, in which to make an allocation decision. This allocation involves deciding which blue asset x_i to use against a red force entity y_j at some time t during this designated period of time in order to restore feasibility. The allocation process produces a number of feasible courses of action (asset-target combinations).

F. DEVELOPING FEASIBLE COURSES OF ACTION

In developing feasible courses of action the methodology produces a number of blue asset to red target combinations. The blue asset will engage the red target at or prior to the decision point t_d. These combinations are based on asset x_i being available to perform a mission. Additionally the time delay between issuing an order to a subordinate unit and that unit beginning execution of the mission is represented. This time delay represents the process of receiving an order, developing an operation order at the subordinate level, issuing that order, preparing for the operation, and finally movement if necessary to execute the mission. These times will be accessed as matrix input to the planning model as notification times $NT_{i,m}$, where m is the mission and i is the type of unit. If already committed, or if the notification time is too great ($t_p + NT_{i,m} > t_d$) then that x_i will not be considered for planning purposes during that period. $NT_{i,m}$ will also decrease the total time period from t_p to t_d a blue asset can be considered when developing the courses of action.

If a blue unit x_i is not committed and notification time of that unit for a mission m is within the time period considered, then that unit can be targeted against a red unit y_j. The attrition rates, ATT_{ij} and ATT_{ji} for the blue asset and red target, respectively, are used to generate new $SIP_{i,t}$ and $SIP_{j,t}$ for each pairing. In this pairing scheme an assumption is that each asset can only be used to carry out a mission against one target at a time. That is for each Δt, each x_i will be targeted against all y_j, and each pairing represents one possible course of action.

When considering these pairings it is possible for a blue asset to engage an enemy unit y_j prior to y_j being in position to accomplish its mission at time $t_{a,j}$. This time of engagement prior to $t_{a,j}$ is designated as t_{eng}. Therefore there are three cases to be considered:

- The increase of power of j, $SIP_{j,t}$, due to movement for the situation $t_p \leq t < t_{eng}$ (Equation 4.11):

$$SIP_{j,t} = ABIP_j \times \exp(B_j \times t) \qquad \text{(eqn 4.11)}$$

- The measure of power of j after engagement by x_i, but prior to $t_{a,j}$, $t_{eng} \leq t \leq t_{a,j}$ (Equation 4.12):
- The decrease of power due to attrition for $t_{a,j} < t \leq t_c$ (Equation 4.13):

$$SIP_{j,t} = SIP_{j,t_{eng}} \times \exp\{(B_j - ATT_{ji}) \times t\} \qquad \text{(eqn 4.12)}$$

$$SIP_{j,t} = SIP_{j,t_{a,j}} \times \exp\{-ATT_{ji} \times (t - t_{a,j})\} \qquad \text{(eqn 4.13)}$$

Additionally a unit that is already involved in an engagement with a committed blue unit may be considered in the generation of courses of action. In the event of this occurrence equation 4.5 is used, and the new ATT_{ji} is added to the previous ATT_{ji}. It is assumed here that the combined attrition rate is additive. If the distance from unit x_i to unit y_j is not within the range of the blue force unit RNG_i, either in terms of movement for a maneuver unit or firing range for a blue artillery unit, then that red unit will not be considered for possible targeting during the time period based on $DIST_j$ for each y_j.

With these considerations in mind the following algorithm is used to generate feasible courses of action.

- Time period is t_p to t_e, $t_s = t_p$ initially.
- For each i, for each m, if $NT_{i,m} + t_p > t_d$ then continue to next m, if all missions m considered then continue to next i.
- For each j if $DIST_j > RNG_i$ then continue to next j.
- Generate $SIP_{i,t}$ for x_i (using Equations 4.2,4.5; if $t < ts$ then use equation $SIP_{i,t} = ABIP_i$).
- Generate corresponding $SIP_{j,t}$ for y_j (using Equations 4.3,4.4,4.5,4.11,or if $t_{eng} < t_{a,j}$ use Equations 4.11,4.12,4.13).
- Store each $SIP_{i,t}$ and $SIP_{j,t}$ for each i,j,t_p ($i = 1,...,I$ and $j = 1,...,J$).
- Increment $t_s = t_p + \Delta t$.
- Continue to step 1 until $NT_{i,m} + t_p > t_d$ for all x_i.

G. SELECTION OF A COURSE OF ACTION TO RESTORE FEASIBILITY

From the feasible courses of action a course of action is selected in order to restore feasibility to the plan. The selection is based on a ratio of red power destroyed to blue power used. That course of action which produces the largest ratio value will be selected. Red power destroyed PD_{ji} is measured as the difference in power at the decision point t_d, between the original $SIP_{j,t}$ and the $SIP_{j,t}$ which reflects the engagement of y_j by x_i in each course of action. The power used PU_{ij} by the blue asset x_i in the course of action is determined by computing the difference between the $SIP_{i,t}$ at t_d for an uncommitted x_i, and the $SIP_{i,t}$ for the engaged x_i using the ATT_{ij} for that course of action.

$$PD_{ji}/PU_{ij} = (SIP_{j_{nc},t_d} - SIP_{j,t_d})/(SIP_{i_{nc},t_d} - SIP_{i,t_d}) \qquad \text{(eqn 4.14)}$$

The ratio of red power destroyed to blue power used is computed for every course of action. That ratio resulting in the largest value is chosen as the course of action to be implemented at the time t_s indicated by the course of action algorithm in order to restore feasibility of the power differential at the decision point t_d. The $SIP_{j,t}$ of the y_j designated as a target in the chosen course of action will be added to those of the other y_j's in order to produce the power of the red force over the decision period. The blue asset x_i indicated in this course of action selection is designated as a committed unit against target y_j, the other member of the pairing. The following algorithm is used to generate the new red and blue force power curves.

- Time period is from t_p to t_e.
- For each $i\varepsilon\{I_{nc}\}$ generate $SIP_{i,t}$ (using Equations 4.2,4.5).
- For each i_{nc} generate $SIP_{i,t}$(using Equations 4.2,4.4).
- For each $j\varepsilon\{J_{nc}\}$ generate $SIP_{j,t}$ (using Equations 4.2,4.5, or 4.11,4.12,4.13).
- For each j_{nc} generate $SIP_{j,t}$(using Equations 4.2,4.4).
- Compute $SIP_{x,t}$ by summing the $SIP_{i,t}$ for each x_i $(i=1,...,I)$
- Compute $SIP_{y,t}$ by summing the $SIP_{j,t}$ for each y_j. $(j=1,...,J)$

At this point in the procedure, feasibility over the entire time period must be checked again using the algorithm for determining feasibility of the plan. If the plan is feasible throughout the time period from t_p to t_e then this becomes the defensive plan for the blue level of command for which it is developed. If the plan is not feasible at some time t_d $(t_p \leq t_d \leq t_e)$, then courses of action will be developed, one will be chosen and integrated into the existing plan and feasibility will be checked again. This selection process continues until the plan is either feasible or all assets have been committed. In the case of all assets being committed, or if the assets available cannot be committed in such a way to restore feasibility, then the planning model will be invoked at the next higher command level in the hierarchy.

H. EXAMPLE OF THE PLANNING MODEL

The purpose of this section is to demonstrate the application of the methodology used in the planning model. The result of this example is a defensive plan for a blue brigade preparing to defend against a red motorized rifle division. The macro plan developed will be a series of times for subordinate blue units assigned missions to be committed against specific red units in order to accomplish the mission received from the higher blue division level.

The scenario for this example is that a blue armor brigade has received an order to defend in its assigned sector against the attack of a red motorized rifle division. Specifically the blue armor brigade is to prevent red forces from advancing past the location of blue brigade's rear boundary over the next eight hour period. The entities subordinate to the brigade (i.e. the troop list representing the assets of the brigade) are received as part of the task organization in the order. The x_i and each respective entity type, BIP_i, $STATE_i$, $DIST_i$, and $SPEED_i$ are given in Table VII. Recall that the $STATE_i$ is the resultant percentage of on hand assets of an entity i.

TABLE VII
BLUE TROOP LIST AND CHARACTERISTICS

x_i	Unit Type	BIP_i	$SPEED_i$	$DIST_i$	$STATE_i$
x_1	Tank Bn.	1000	10 Km/hr	20 Km	1.00
x_2	Tank Bn.	1000	10 Km/hr	20 Km	1.00
x_3	Tank Bn.	1000	10 Km/hr	20 Km	1.00
x_4	Artillery Battalion	800	10 Km/hr	20 Km	1.00
x_5	Helicopter Company	600	40 Km/hr	20 Km	1.00

Correspondingly the intelligence portion of the order, which represents that information received from the intelligence model, contains a similar set of information for each y_j. For this example the units of the division only include maneuver units. This information is given in Table VIII.

TABLE VIII

RED TROOP LIST AND CHARACTERISTICS

x_j	Unit Type	BIP_j	$SPEED_j$	$DIST_j$	$STATE_j$
y_1	MRR	3000	10 Km/hr	45 Km	1.00
y_2	MRR	3000	10 Km/hr	45 Km	1.00
y_3	MRR	3000	10 Km/hr	20 Km	1.00
y_4	Tank Regiment	3600	10 Km/hr	20 Km	1.00
y_5	Ammunition Company	100	10 Km/hr	50 Km	1.00

Additionally through the macro plan there is an initial allocation of units to defend on the FEBA, based on avenues of approach. In this example blue tank battalions x_1 and x_2 have been committed to defending along the FEBA. This initial allocation represents the unit positioning model results by McLaughlin [Ref. 3]. Those units allocated to defense on the FEBA are designated as committed entities, whereas, all others are not committed. Intelligence further indicates the currently perceived positions of the enemy forces within the brigade's sector. Since estimate of the positions and the most likely intent of the enemy units at those positions are known, the matrix of values $K_{i,m}$ pertaining to mission and the type entity based on adversaries can be accessed and linked to blue entities. The relative positions of red and blue units in sector are shown in Figure 4.4.

All distances from the FEBA for both red and blue units are are determined for the sector. Since power is measured over time the $DIST_i$ and $SPEED_i$ are used to indicate where a unit is in time and the forecasted time of arrival $t_{a,i}$ at the position where the entity will accomplish its assigned mission. For the case of noncommitted units, this would be its most likely mission. Similarly this same methodology is used for all y_j.

It is assumed that the usage rates of entities x_i given any mission m are known. These usage rate matrices $U_{i,m}$ describe the rate at which entity i uses logistics assets

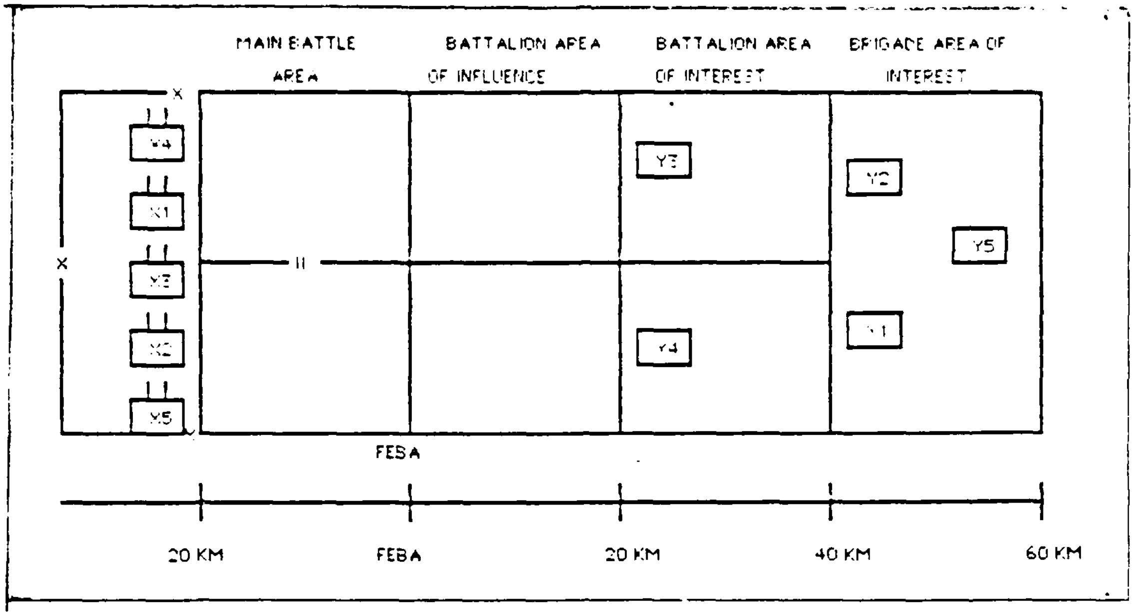

Figure 4.4 Initial Situation in Sector.

such as fuel, and ammunition given it has the mission m. In terms of the model these usage rate matrices, $U_{i,m}$, are accessed and updated based on logistics input from the execution model. Likewise similar information about usage rates $U_{j,m}$ are estimated for red entities y_j based on input from the intelligence model and previously known data. The attrition rate matrices ATT_{ij} and ATT_{ji} are also accessed and updated based on input from the execution model.

Through these various input parameters the associated red and blue force power curves, $SIP_{y,t}$ and $SIP_{x,t}$, respectively, are generated and are shown graphically in Figure 4.5 (see Appendix D).

From the generation of the initial power curves for the red and blue force the defensive planning process is implemented. The estimate of the situation process developed earlier in this chapter is used. The first step of the estimate process is to determine initial mission feasibility. In determining mission feasibility the difference in power levels for the brigade's sector. This difference curve is shown in Figure 4.6.

This figure indicates that with two tank battalions (x_1 and x_2) initially committed to the FEBA battle against the first echelon regiments (y_3 and y_4) and counting uncommitted units x_3, x_4, and x_5 that the initial plan becomes infeasible at 4.3 hours. Infeasibility refers to violation of the upper threshold value of T_u = 1000 STAPOWS.

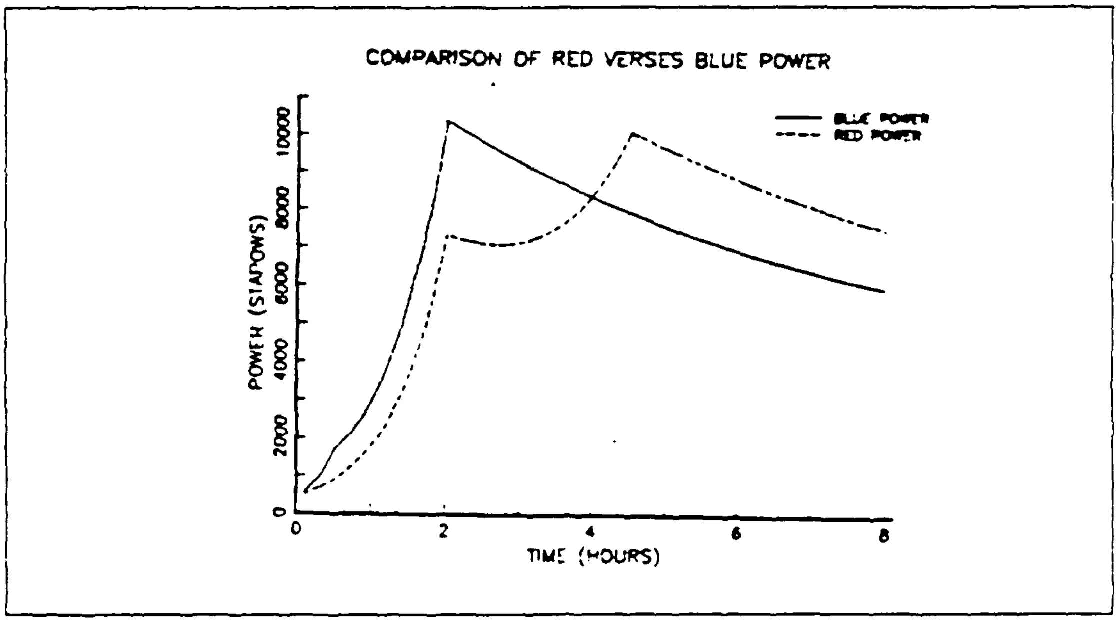

Figure 4.5 Red and Blue Force Power Curves.

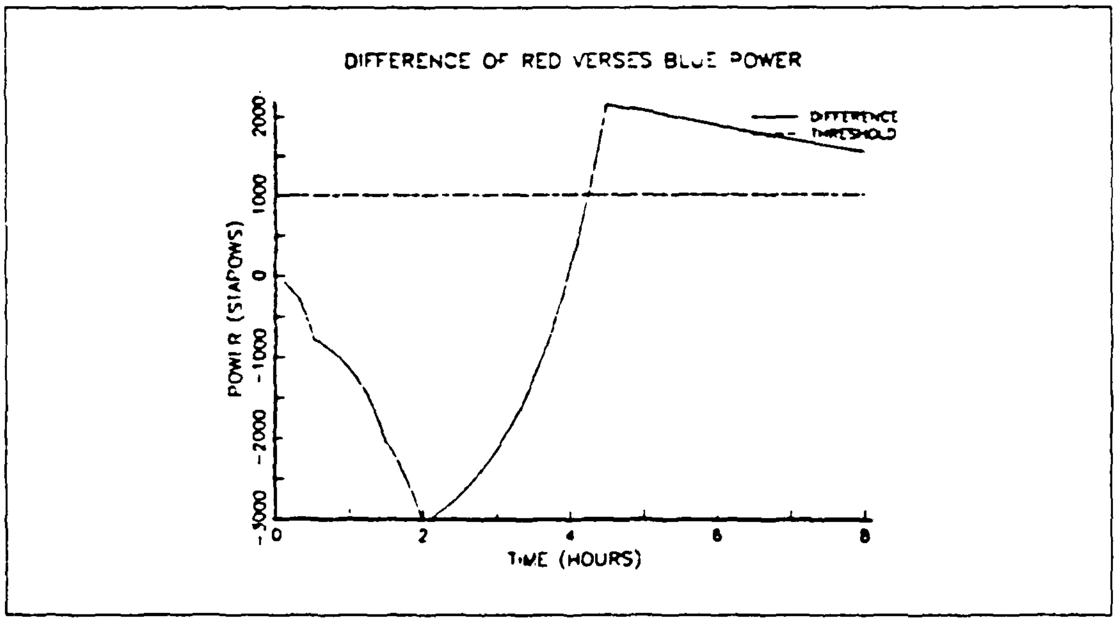

Figure 4.6 Power Difference Between Red and Blue Forces in Sector.

This time coincides approximately with the arrival of red second echelon units y_1 and y_2. The algorithm for determining feasibility is used to determine if committing units

x_3, x_4, and x_5 later will cause an infeasibility earlier than $t_d = 4.3$ hours (see Appendix D). This assumes those units are uncommitted earlier. Indeed through the use of the algorithm if the power corresponding to those x_i not committed were used later then infeasibility of the plan occurred at $t_d = 2$ hours (see Table IX).

TABLE IX
EARLIEST TIME OF INFEASIBILITY

$t_p + \Delta t$	t_d	$DIFF_{t_d} - T_u$ (STAPOWS)
0.0 hrs.	4.3 hrs.	261
0.5 hrs.	4.5 hrs.	1131
1.0 hrs.	4.5 hrs.	1109
1.5 hrs.	4.5 hrs.	1088
2.0 hrs.	2.0 hrs.	100

Courses of action must be developed to restore feasibility at the first point at which the difference exceeded the upper threshold value T_u. An example of this in Table IX occurred when the uncommited units did not start to execute missions untill $t_p + \Delta = 2$ hours. The resultant threshold violation was 100 STAPOWS above T_u which occurred at $t_d = 2$ hours. In order to use the algorithm for developing courses of action, notification times $NT_{i,m}$, are accessed through the functional submodels appropriate with each type i entity. For example x_4 is the artillery unit therefore the $NT_{i,m}$ associated with that unit will be accessed from the artillery submodel. Once the $NT_{i,m}$ have been accessed the algorithm for developing feasible courses of action is used (see Appendix D). This generates all the possible asset i, given mission m, against target j pairings between times $t_p = 0$ to $t_d = 2$ hours. For the purposes of the example there are four possible missions considered for each i. These missions are defend, delay, attack, and prosecute. Prosecute is used here to describe units, other than maneuver units such as armor or infantry, whose mission is to fire at the enemy, such as artillery. The Δt used in the algorithm is .5 hours. There were fourteen courses of action generated, of those six were feasible courses of action, that is those which restored feasibility at $t_d = 2$ hours (see Table X).

TABLE X
FEASIBLE COURSES OF ACTION

Feasible Course of Action	t_{eng}	x_i	y_j	$\frac{PD_{ji}}{PU_{ij}}$
1	1.5 hrs.	x_4	y_3	57.4
2	1.5 hrs.	x_4	y_4	28.5
3	0.5 hrs.	x_5	y_3	1.41
4	0.5 hrs.	x_5	y_4	2.49
5	1.0 hrs.	x_5	y_4	2.76
6	1.5 hrs.	x_5	y_4	3.59

The feasible course of action which has the largest ratio of red power destroyed to blue power used, PD_{ji}/PU_{ij}, was to use the artillery unit x_4 to prosecute the motorized rifle regiment, y_3, with a time of engagement of $t_{eng} = 1.5$ hours. The algorithm for generation of the new red force power curve, $SIP_{y,t}$, and blue force power curve, $SIP_{x,t}$, is used to provide a graphical representation of the implementation of the chosen feasible course of action as shown in Figure 4.7. A pictorial view of the sector showing predicted movement of units red and blue and the prosecution of the motorized rifle regiment y_3 are shown in Figure 4.8.

Although feasibility has been restored to the plan at the point $t_d = 2$ hours, the check for feasibility throughout the time period of the plan is required. The algorithm for determining feasibility of the initial mission now is used to determine feasibility of the new plan. A Δt of .5 hours is used for the time stepping process. After time stepping through the plan from $t_p = 0$, to $t_e = 8$ hours, the earliest violation of threshold value T_u occurred at a $t_d = 4.5$ hours. This time coincides with the arrival of the second echelon regiments y_1 and y_2.

Again feasible courses of action are developed to restore feasibility of the plan with respect to the difference in power levels between the red and blue force in the brigade's sector. It is noted here that the artillery unit is again considered for use in

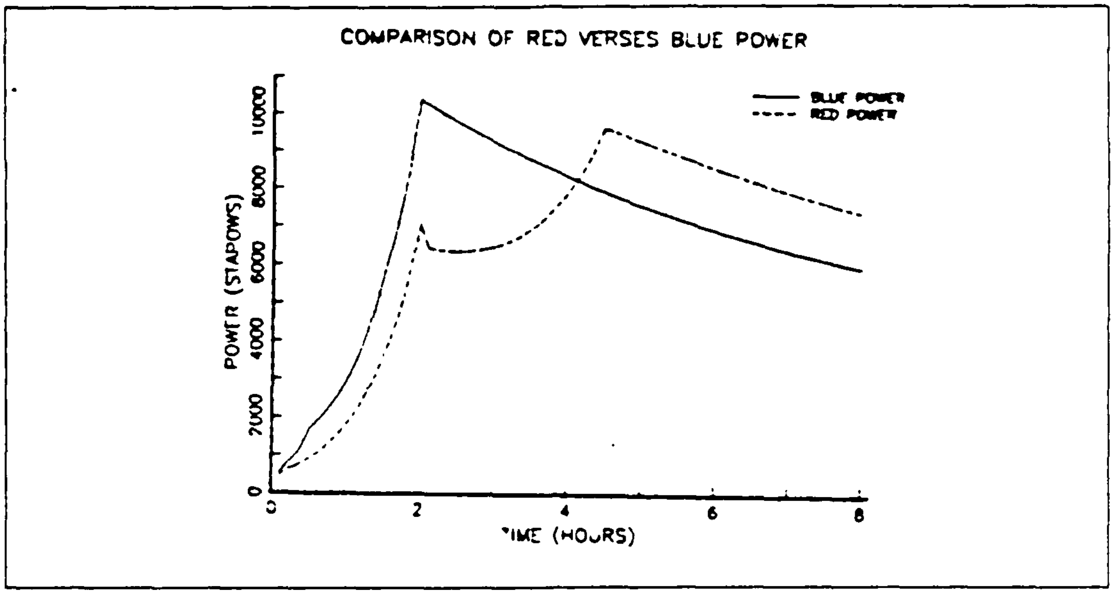

Figure 4.7 New Force Power Curves After First Decision.

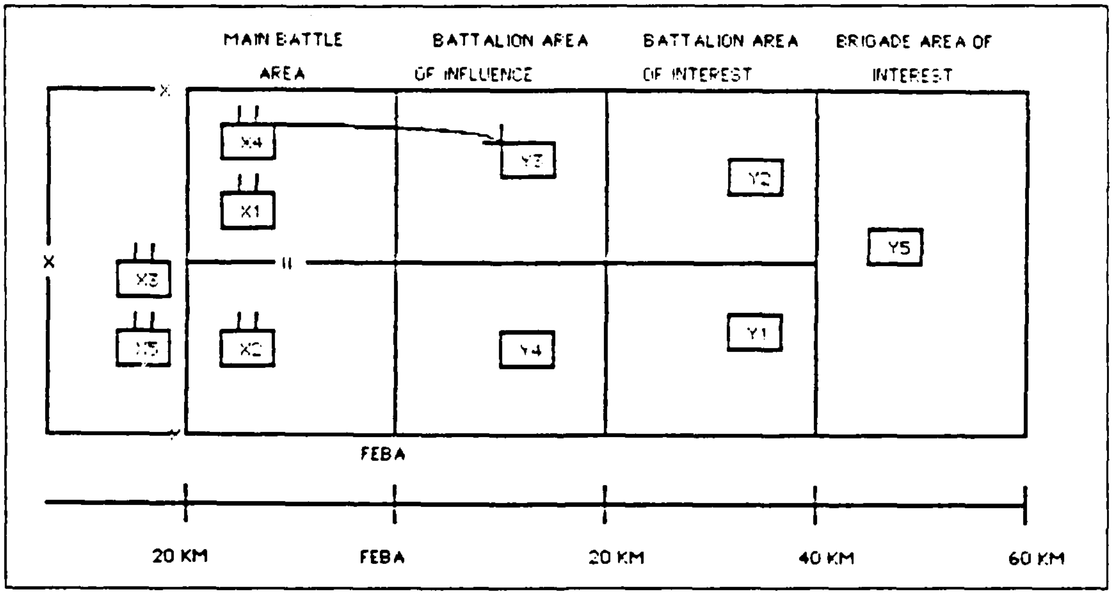

Figure 4.8 View of Brigade Sector Implementing First Decision.

the development of courses of action. This represents that process in the real world of redirecting of fires against an enemy target beyond the FEBA in order to attrite that unit prior to its arrival at the FEBA. This use of planning for artillery fires throughout a defensive plan is in keeping with the planning process prescribed by the U.S. Army [Ref. 5]. From the feasible courses of actions developed the course of action resulting in the largest ratio which also satisfied the necessary red power destroyed to restore feasibility is chosen. In the case of this decision two courses were necessary in order to restore feasibility. The two courses of action were to commit the reserve tank battalion x_3 against the second echelon motorized rifle regiment y_1 with a $t_{eng} = 4$ hours, and to use the artillery unit x_4 against the other second echelon motorized rifle regiment y_2 at $t_{eng} = 2.5$ hours. After implementing this course of action in the defensive plan the resultant red and blue force power curves are shown in Figure 4.9.

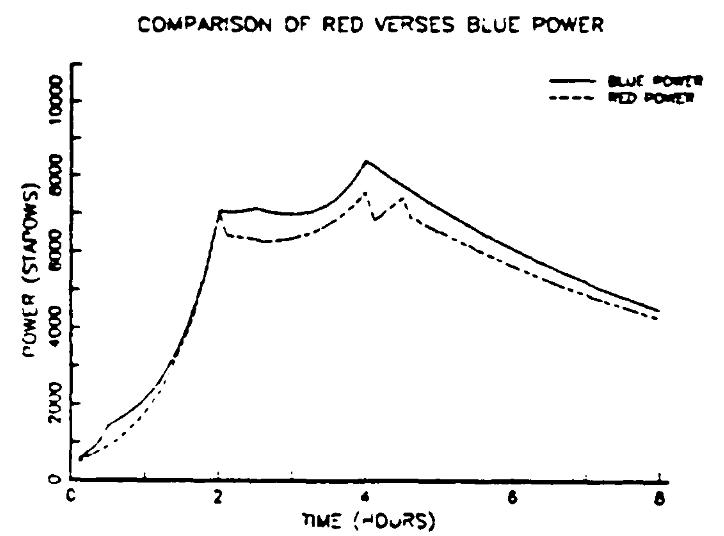

Figure 4.9 Force Power Curves After Second Decision.

A pictorial representation of the commitment of blue forces and red forces in the brigade sector are shown in Figure 4.10.

Since a new plan is generated, feasibility of the new plan must be checked through the time period from $t_p = 0$, to $t_e = 8$ hours. There was only one asset, the helicopter unit x_5 remaining to be time stepped with a $\Delta t = .5$ hours through the decision period. This process did not produce any violations of the threshold value. Therefore the last plan developed is a feasible macro plan and is list in Table XI.

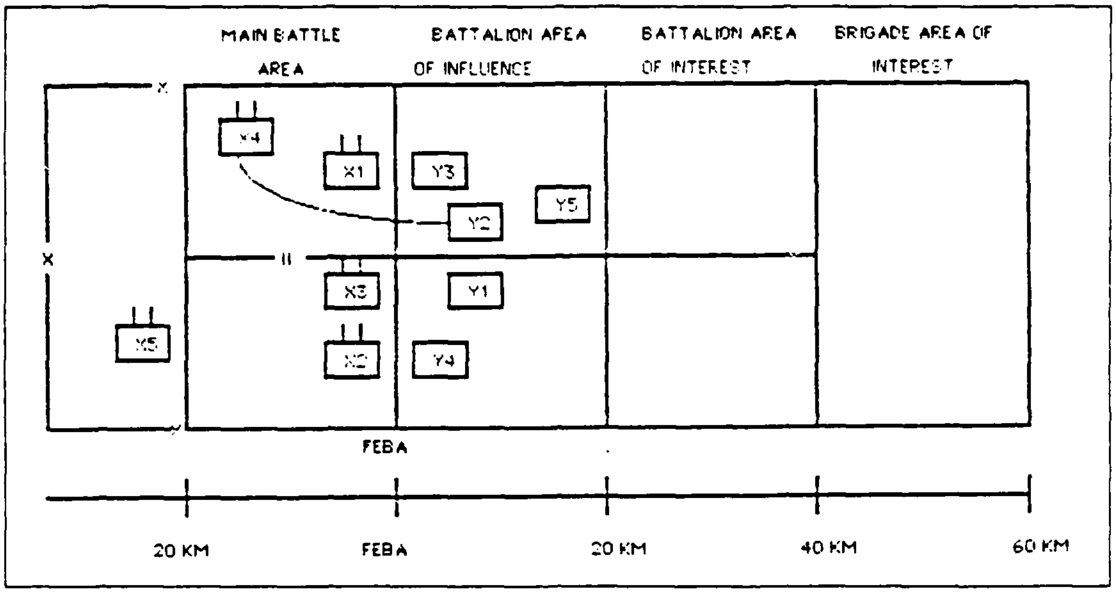

Figure 4.10 Brigade Sector After Second Decision.

TABLE XI
THE DEFENSIVE PLAN

Time	Event
1.5 hrs.	x_4 fires on y_3
2.0 hrs.	x_1 defends on FEBA against y_3
2.0 hrs.	x_2 defends on FEBA against y_4
2.5 hrs.	x_4 fires on y_2
4.0 hrs.	commit x_5 to defend on FEBA against y_1

This final macro plan represents an example of the output of the planning model methodology. It follows a recursive process linked to the estimate of the situation. The steps of this process are as follows:

- Determination of initial mission feasibility.

- Designation of decision point.
- Developing feasible courses of action.
- Selection of a course of action to restore feasibility.

The example shown in this section demonstrates the development of a plan for the committment of ground force units over time for use as the brigade macro plan. Also demonstrated is the applicability of using the proposed planning model methodology as part of the macro planning process in ALARM.

V. SUMMARY

A. CONCLUSIONS

This thesis has achieved the objectives which were established in the initial chapter. Specifically this thesis has developed a model for use in generating tactical boundaries (zones of action) through avenue of approach generation and a model to generate a plan representing ground force missions over time. The models were both demonstrated through the use of examples.

In developing the means to generate tactical boundaries through avenues of approach a series of algorithms were used to:

- Eliminate arcs (routes) which are not capable to sustain the movement of advancing red battalions.
- Develop a connected network after those infeasible arcs were eliminated.
- Generate zones on the network by which concentrations of flow rate are used to determine zones of action, corridors, of advancing red regiments.
- Generate "dummy" nodes to represent the flow of routes crossing zones where previously the flow rate could not be measured.
- Generate boundaries as a representation of the zones of action.
- Generate regimental avenues of approach as a series of arcs and nodes through the corridors.

Using this series of algorithms a zone of action of one MRR was designated and the regimental avenue of approach within that zone was determined.

The planning model represents the defensive planning process which upon receipt of an order from the next higher level of command, develops a plan over a time horizon for subordinate ground force units. This is accomplished through a series of algorithms which:

- Determine initial mission feasibility.
- Designate a decision point.
- Develop feasible courses of action.
- Select a course of action to restore feasibility.

Through an example these algorithms were used to generate a defensive plan for a brigade size unit facing a motorized rifle division in the attack.

B. FUTURE DIRECTIONS

Several areas of future research need to be explored in order to incorporate these models into the framework of ALARM. The model for generating zones of action and avenues of approach requires further development. Specifically the model produces results relative to having a series of good movement routes available in order to produce zones of action and avenues of approach. Sensitivity analysis should be conducted to determine a range of input parameters for the process of eliminating infeasible arcs. A variety of networks should be studied to identify the applicability of the current methodology and deficiencies which may exist. The method of generating boundaries to represent zones of action needs further development to accommodate irregularities which might exist within the terrain network. A possible alternative to the method proposed is to create artificial nodes on all arcs that cross the zone limits, then using these nodes to measure flow rates at the limits of each zone. The planning model requires testing using many different situations in terms of red and blue force composition, and various battlefield situations.

APPENDIX A
LIST OF ARCS AND CHARACTERISTICS

This appendix contains the list of arcs and the corresponding arc characteristics. This list represents the network used for the example in Chapter 3.

H_j	Head node identification number.
T_j	Tail node identification number.
D_j	Distance from head node to tail node.
RC_j	Integer describing route class type.
OC_j	Integer describing off route trafficability.
W_j	Width of the route represented by the arc.

H_j	T_j	D_j	RC_j	OC_j	W_j	H_j	T_j	D_j	RC_j	OC_j	W_j
61	3	1.0	8	1	1.0	28	35	1.8	8	2	1.0
62	4	1.0	8	1	1.0	28	33	2.5	4	1	0.4
1	5	0.2	9	1	1.0	29	28	2.0	7	3	3.0
2	8	3.5	4	1	1.0	29	31	2.0	7	3	3.0
3	2	2.0	1	1	1.0	30	29	1.0	8	1	1.0
3	8	3.0	8	2	3.0	30	31	2.0	7	3	3.0
4	3	2.5	1	1	1.0	31	32	1.0	1	1	1.0
4	7	1.0	5	1	1.0	31	42	4.5	8	2	1.0
5	4	2.5	1	1	1.0	31	33	2.5	8	2	0.5
5	6	1.5	2	1	1.0	32	28	3.0	7	3	3.0
6	10	1.5	2	1	1.0	32	33	1.5	1	1	0.1
6	13	3.0	8	3	1.0	33	35	2.0	7	3	3.0
7	10	2.0	4	1	1.0	33	42	3.5	7	3	3.0
7	9	3.4	4	1	1.0	33	34	2.0	1	1	0.1
8	14	2.0	4	1	1.0	36	34	1.8	8	2	1.0
8	15	1.9	6	2	1.0	34	43	3.0	1	2	0.5

8	9	2.2	4	1	1.0	35	34	1.5	8	3	0.1
8	6	3.3	4	1	1.0	35	36	2.0	8	3	0.5
9	16	2.2	8	1	1.0	36	45	2.0	7	3	3.0
9	19	3.3	4	1	0.1	36	44	2.5	2	2	0.5
10	12	1.5	2	1	0.1	37	45	3.4	7	3	3.0
10	11	1.5	8	1	1.0	37	40	1.0	8	2	1.0
11	12	1.7	4	1	1.0	37	39	1.0	1	2	1.0
11	13	2.3	6	1	0.1	37	38	1.0	8	2	1.0
12	18	3.0	2	1	1.0	38	45	3.5	2	3	0.5
12	19	1.7	4	1	0.5	38	39	0.7	2	3	0.1
12	20	3.0	4	1	1.0	38	41	1.0	7	3	3.0
12	21	4.5	8	2	1.0	38	48	3.5	7	3	3.0
13	20	1.8	6	1	1.0	38	49	3.5	7	3	3.0
13	22	2.1	8	2	1.0	38	50	3.8	7	3	3.0
14	15	0.6	3	2	0.8	38	47	3.2	7	3	3.0
15	16	2.5	3	2	0.5	39	40	0.6	2	1	0.5
15	30	3.0	7	3	3.0	40	41	1.0	1	1	1.0
15	31	5.0	7	3	3.0	41	46	1.3	1	3	0.8
16	30	2.2	7	2	0.5	42	43	3.0	1	3	0.1
16	17	1.7	9	1	0.5	43	44	0.5	1	1	1.0
17	29	3.0	7	3	3.0	43	56	3.5	1	2	0.5
17	28	2.0	4	1	0.5	44	57	4.1	3	2	0.5
17	18	2.0	3	2	0.1	44	48	3.0	8	4	1.0
17	19	2.3	4	1	0.5	45	44	2.5	2	1	0.5
18	25	1.5	5	1	0.5	46	51	2.0	1	3	1.0
18	26	1.2	2	1	1.0	46	47	1.0	7	3	3.0
18	21	3.3	8	2	1.0	47	51	2.0	8	2	1.0
20	21	1.5	6	1	1.0	47	50	1.4	7	3	3.0
20	22	1.5	1	1	1.0	47	52	2.5	8	2	1.0
21	23	3.0	7	3	1.0	48	49	1.5	8	3	1.0
21	24	2.5	7	3	3.0	48	55	1.5	6	3	1.0
21	25	3.3	8	2	1.0	48	57	4.0	6	2	0.5
22	21	1.5	7	3	3.0	49	50	1.6	8	2	0.1
22	23	2.5	7	3	3.0	49	55	2.0	1	2	0.5
23	40	2.3	7	3	3.0	50	55	2.7	1	2	0.5

23	37	2.8	7	3	3.0	50	52	2.0	1	2	0.5
23	24	2.7	7	3	3.0	51	52	1.0	6	1	1.0
24	37	2.3	1	1	0.5	52	53	0.8	6	1	0.5
24	45	5.1	7	3	3.0	52	54	1.3	6	1	1.0
24	36	3.8	8	1	1.0	53	60	1.0	6	1	0.1
25	24	1.6	8	1	1.0	53	54	1.1	8	1	1.0
25	27	1.2	8	1	1.0	54	60	1.5	8	1	1.0
26	25	0.8	6	1	1.0	54	55	3.2	6	1	0.5
26	27	1.2	2	1	1.0	55	59	2.5	7	3	3.0
26	28	2.0	8	3	1.0	55	58	1.5	7	3	3.0
27	24	3.3	9	1	1.0	55	57	3.7	4	1	0.5
27	36	4.0	2	1	0.4	56	57	2.0	1	1	0.5
28	27	1.0	4	1	0.1						

The following codes and what each represents were used for the characteristics of route class RC_j and off road class OC_j of any arc j., in the case of the off road class it explains what type of vehicles are supported by the terrain.

Route Classification

Integer Code	Arc Type
1	Autobahn
2	Autobahn and Railroad
3	Railroad
4	Concrete Road
5	Asphalt Road
6	Dirt Road
7	Forest
8	Open Country
9	Road and Railroad
10	Bridge, Tunnel

Off-Road Characteristics

Integer Code	Vehicle Type Supported

1	Heavy Tank
2	Medium Tank, Fighting Vehicle
3	Heavy Truck
4	Light Truck
5	Dismounted Troops

APPENDIX B

COMPUTER PROGRAMS FOR AVENUE OF APPROACH GENERATION

This appendix contains the computer progams used to support the algorithms in Chapter 3. The first program is used to compute the flow rate RFR for each arc in the example network (see Appendix A). In addition it also determines if each arc is feasible based on the input of a route class NRC, and off route class NOC, and the minimum acceptable flow rate.

```
      INTEGER H(127),T(127)
      DIMENSION D(127),NRC(127),NOC(127),W(127)
      DIMENSION RFR(127),ID(127)
      DIMENSION TR(127),NFR(127)
      OPEN(UNIT=28,FILE='NETD')
      OPEN(UNIT=34,FILE='NEWO')
      OPEN(UNIT=37,FILE='NETO')
      DO 10 I=1,127
          READ(28,5) H(I),T(I),D(I),NRC(I),NOC(I),W(I)
 5       FORMAT(4X,I2,3X,I2,3X,F3.1,2X,I1,4X,I1,4X,F3.1)
 10   CONTINUE
      SP=5.0
      DW=1.0
      DD=3.0
      DO 19 I=1,127
          RFR(I)=0.0
 19   CONTINUE
      DO 20 I=1,127
          RFR(I)=(SP*W(I))/3.0
 20   CONTINUE
      DO 30 I=1,127
      IF(NRC(I).NE.7)THEN
          IF(NOC(I).GE.4) GOTO 25
          IF(RFR(I).LE.0.5) GOTO 25
          ID(I)=1
      ELSE
 25      ID(I)=0
      END IF
 30   CONTINUE
      DO 60 I=1,127
          TR(I)=RFR(I)*100
          NFR(I)=IFIX(TR(I))
 60   CONTINUE
      LCOST=0
      DO 70 I=1,127
          WRITE(34,65) H(I),T(I),H(I),T(I),LCOST,NFR(I)
          WRITE(34,65) T(I),H(I),T(I),H(I),LCOST,NFR(I)
 65      FORMAT(2I2,2X,2I6,2X,2I10)
 70   CONTINUE
      DO 115 I=1,127
      IF((ID(I).NE.0).AND.(RFR(I).GE.0.5))THEN
          WRITE(37,110) H(I),T(I),RFR(I)
 110     FORMAT(2X,I2,2X,I2,2X,F5.2)
      END IF
 115  CONTINUE
      STOP
      END
```

This program takes the output of feasible arcs and nodes from the previous program and makes a connected network from it. The process of making a connected network from one which is not is described in the algorithm listed in Chapter 3.

```
      INTEGER H(85),T(85),ID(85)
      DIMENSION RFR(85)
      OPEN(UNIT=27,FILE='NETO')
      OPEN(UNIT=31,FILE='NEO1')
      DO 10 I=1,85
         READ(27,5) H(I),T(I),RFR(I)
      PRINT *, H(I),T(I),RFR(I)
 5       FORMAT(2X,I2,2X,I2,2X,F5.2)
 10   CONTINUE
      DO 19 I=1,85
         ID(I)=1
 19   CONTINUE
      DO 80 I=1,85
         IF(ID(I).EQ.0)GOTO 80
         IF((H(I).EQ.1).OR.(H(I).EQ.61).OR.(H(I).EQ.62))THEN
                ID(I)=1
                GOTO 80
         END IF
 71      DO 75 J=1,85
                IF(H(I).EQ.T(J))THEN
                       ID(I)=1
                       GOTO 80
                ELSE
                       ID(I)=0
                END IF
 75      CONTINUE
 80   CONTINUE
      DO 95 I=1,85
         IF(ID(I).EQ.0)GOTO 95
         IF(T(I).GE.57)THEN
                ID(I)=1
                GOTO 95
         END IF
 85      DO 90 J=1,85
                IF((T(I).EQ.H(J)).AND.(ID(J).NE.0))THEN
                       ID(I)=1
                       GOTO 95
                ELSE
                       ID(I)=0
                END IF
 90      CONTINUE
 95   CONTINUE
      DO 115 I=1,85
      IF(ID(I).NE.0)THEN
         WRITE(31,110) H(I),T(I),RFR(I),ID(I)
         PRINT *, H(I),T(I),RFR(I),ID(I)
 110     FORMAT(2X,I2,2X,I2,2X,F5.2,2X,I1)
      END IF
 115  CONTINUE
      STOP
      END
```

This program uses the connected network developed in the previous program as input, with the respective arc and node characteristics as well. From this network zones are determined based on a zone distance input. Once zones have been designated then "dummy" nodes are generated, if necessary. The network with zones is then divided into corridors (zones of action) and from these a regimental path or avenue is determined.

```
      INTEGER H(74),T(74)
      DIMENSION RFR(74)
      DIMENSION N(53),ID(53)
      DIMENSION IG(11,10)
      DIMENSION NIG(11,10)
      DIMENSION IDG(11,10)
      DIMENSION RF(11,10)
      DIMENSION IV(53),IH(53)
      DIMENSION NT(74),NH(74)
      DIMENSION NDIFF(74)
      DIMENSION NV(10),NVT(10),NVH(10)
      DIMENSION NIH(10),NIHT(10),NIHH(10)
      DIMENSION NUB(10),NLB(10),NUV(10)
      DIMENSION NLV(10),NVC(10),NLC(10),NRC(10)
      DIMENSION NRR(10)
      DIMENSION RFN(10),NRIH(10),NRIV(10)
      OPEN(UNIT=14,FILE='NE01')
      OPEN(UNIT=15,FILE='NE04')
      OPEN(UNIT=16,FILE='NE05')
      OPEN(UNIT=17,FILE='NE06')
      DO 10 I=1,68
         READ(14,5) H(I),T(I),RFR(I)
 5       FORMAT(2X,I2,2X,I2,2X,F5.2)
10    CONTINUE
      DO 20 I=1,47
         READ(15,15) N(I),ID(I)
15       FORMAT(2(2X,I2))
20    CONTINUE
      DO 25 I=1,47
         READ(16,23) IV(I),IH(I)
23       FORMAT(2(2X,I3))
25    CONTINUE
      DO 35 I=1,11
         DO 30 J=1,10
            IG(I,J)=0
30    CONTINUE
```

This portion of the code generates the zones on the network.

```
35    CONTINUE
      M=0
      DO 45 I=720,920,20
         M=M+1
         M1=0
         DO 40 K=1,47
               IF((IV(K).GE.I).AND.(IV(K).LT.(I+20)))THEN
                     M1=M1+1
                     IG(M,M1)=N(K)
               END IF
40       CONTINUE
45    CONTINUE
      DO 55 I=1,10
         WRITE(17,50) (IG(J,I),J=1,11)
50       FORMAT(11(2X,I2))
55    CONTINUE
      DO 70 I=1,11
         DO 65 J=1,10
               DO 60 K=1,49
                     IF(IG(I,J).EQ.N(K))THEN
```

```
                    NIG(I,J)=IH(K)
                 ELSE IF(IG(I,J).EQ.0)THEN
                    NIG(I,J)=0
                 END IF
60          CONTINUE
65       CONTINUE
70    CONTINUE
      DO 80 I=1,10
         WRITE(17,75) (NIG(J,I),J=1,11)
75       FORMAT(11(2X,I3))
80    CONTINUE
```

At this point the zone matrix of nodes is ordered by location.

```
      DO 95 I=1,11
         NM=0
         NM=10-1
         DO 90 K=1,NM
            JM=10-K
            DO 85 J=1,JM
               IF(NIG(I,J).GT.NIG(I,J+1))GOTO 85
               NEW=NIG(I,J)
               NW=IG(I,J)
               NIG(I,J)=NIG(I,J+1)
               IG(I,J)=IG(I,J+1)
               NIG(I,J+1)=NEW
               IG(I,J+1)=NW
85          CONTINUE
90       CONTINUE
95    CONTINUE
      DO 97 I=1,10
         WRITE(17,96) (NIG(J,I),J=1,11)
96       FORMAT(11(2X,I3))
97    CONTINUE
      DO 99 I=1,10
         WRITE(17,98) (IG(J,I),J=1,11)
98       FORMAT(11(2X,I2))
99    CONTINUE
      DO 105 I=1,11
         DO 103 J=1,10
            RF(I,J)=0.0
103      CONTINUE
105   CONTINUE
      DO 130 I=1,11
         DO 120 J=1,10
            M=0
            DO 110 K=1,68
               IF(IG(I,J).EQ.T(K))THEN
                  M=M+1
                  IDG(I,J)=M
                  RF(I,J)=RF(I,J)+RFR(K)
               ELSE IF(IG(I,J).EQ.0)THEN
                  IDG(I,J)=0
               END IF
110         CONTINUE
120      CONTINUE
130   CONTINUE
      DO 140 I=1,10
         WRITE(17,135) (IDG(J,I),J=1,11)
135      FORMAT(11(2X,I2))
140   CONTINUE
      DO 145 I=1,10
         WRITE(17,143) (RF(J,I),J=1,11)
143      FORMAT(11(2X,F5.2))
145   CONTINUE
      DO 147 K=1,68
         NT(K)=0
         NH(K)=0
```

```
147 CONTINUE
    DO 165 I=1,11
        DO 160 J=1,10
        DO 155 K=1,68
               IF(IG(I,J).EQ.T(K))THEN
                      NT(K)=I
               ELSE IF(IG(I,J).EQ.H(K))THEN
                      NH(K)=I
               END IF
155      CONTINUE
160      CONTINUE
165 CONTINUE
    DO 180 K=1,68
        NDIFF(K)=NH(K)-NT(K)
180 CONTINUE
    DO 190 K=1,68
        WRITE(17,185) H(K),T(K),NH(K),NT(K),NDIFF(K)
185      FORMAT(5(2X,I2))
190 CONTINUE
```

Here a decision if "dummy" nodes are necessary is made, and then those nodes are generated where needed.

```
    M1=0
    M=0
    DO 200 K=1,68
        M1=M1+1
        IF(NDIFF(K).EQ.2)THEN
               M=M+1
        END IF
200 CONTINUE
    M6=0
    DO 205 K=1,68
        IF(NDIFF(K).EQ.2)THEN
        DO 203 I=1,47
               IF(H(K).EQ.N(I))THEN
                      M6=M6+1
                      NIHH(M6)=IH(I)
                      NVH(M6)=IV(I)
               END IF
               IF(T(K).EQ.N(I))THEN
                      NIHT(M6)=IH(I)
                      NVT(M6)=IV(I)
               END IF
203      CONTINUE
        END IF
205 CONTINUE
    DO 206 I=1,6
206 CONTINUE
    DO 207 I=1,M6
        IF(NVH(I).GT.NVT(I))THEN
               NV(I)=(NVH(I)-NVT(I))/2
               NV(I)=NV(I)+NVT(I)
        ELSE IF(NVH(I).EQ.NVT(I))THEN
               NV(I)=NVH(I)
        ELSE
               NV(I)=(NVT(I)-NVH(I))/2
               NV(I)=NV(I)+NVH(I)
        END IF
        IF(NIHH(I).GT.NIHT(I))THEN
               NIH(I)=(NIHH(I)-NIHT(I))/2
               NIH(I)=NIH(I)+NIHT(I)
        ELSE IF(NIHH(I).EQ.NIHT(I))THEN
               NIH(I)=NIHH(I)
        ELSE
               NIH(I)=(NIHT(I)-NIHH(I))/2
               NIH(I)=NIH(I)+NIHH(I)
```

```
        END IF
207 CONTINUE
      M2=M1+M
      DO 210 K=1,M2
        IF(K.GT.68)THEN
              T(K)=0
              H(K)=0
              RFR(K)=0
              NH(K)=0
              NT(K)=0
              NDIFF(K)=0
        END IF
210 CONTINUE
      M4=0
      M3=47+M
      M7=0
      DO 220 K=1,M3
        IF(K.GT.47)THEN
              M4=M4+1
              N(K)=62+M4
              IV(K)=NV(M4)
              IH(K)=NIH(M4)
        END IF
        WRITE(17,219) N(K),IV(K),IH(K)
219     FORMAT(2X,I2,2X,I3,2X,I3)
220 CONTINUE
      M=0
      DO 230 K=1,74
        IF(NDIFF(K).EQ.2)THEN
              M=M+1
              MN=68+M
              T(MN)=T(K)
              T(K)=62+M
              H(MN)=62+M
              RFR(MN)=RFR(K)
              NT(MN)=NT(K)
              NH(MN)=NT(K)+1
              NT(K)=NT(K)+1
              NDIFF(MN)=NDIFF(K)-1
              NDIFF(K)=NDIFF(K)-1
        END IF
      WRITE(17,225) H(K),T(K),RFR(K),NH(K),NT(K),NDIFF(K)
225 FORMAT(2X,I2,2X,I2,2X,F5.2,2X,I2,2X,I2,2X,I2)
230 CONTINUE
      M=0
      DO 245 I=720,920,20
        M=M+1
        M1=0
        DO 240 K=1,53
              IF((IV(K).GE.I).AND.(IV(K).LT.(I+20)))THEN
                    M1=M1+1
                    IG(M,M1)=N(K)
              END IF
240     CONTINUE
245 CONTINUE
      DO 270 I=1,11
        DO 265 J=1,10
              DO 260 K=1,53
                    IF(IG(I,J).EQ.N(K))THEN
                          NIG(I,J)=IH(K)
                    ELSE IF(IG(I,J).EQ.0)THEN
                          NIG(I,J)=0
                    END IF
260           CONTINUE
265     CONTINUE
270 CONTINUE
      DO 295 I=1,11
        NM=0
        NM=10-1
```

```
      DO 290 K=1,NM
            JM=10-K
            DO 285 J=1,JM
                  IF(NIG(I,J).GT.NIG(I,J+1))GOTO 285
                  NEW=NIG(I,J)
                  NW=IG(I,J)
                  NIG(I,J)=NIG(I,J+1)
                  IG(I,J)=IG(I,J+1)
                  NIG(I,J+1)=NEW
                  IG(I,J+1)=NW
285         CONTINUE
290      CONTINUE
295 CONTINUE
      DO 297 I=1,10
         WRITE(17,296) (NIG(J,I),J=1,11)
296      FORMAT(11(2X,I3))
297 CONTINUE
      DO 299 I=1,10
         WRITE(17,298) (IG(J,I),J=1,11)
298      FORMAT(11(2X,I2))
299 CONTINUE
      DO 305 I=1,11
         DO 303 J=1,10
            RF(I,J)=0.0
303      CONTINUE
305 CONTINUE
```

This portion of the code is used to select boundaries based on arc flow rates, after which the regimental avenue of approach is determined.

```
      DO 330 I=1,11
         DO 320 J=1,10
            M=0
            DO 310 K=1,74
                  IF(IG(I,J).EQ.T(K))THEN
                        M=M+1
                        IDG(I,J)=M
                        RF(I,J)=RF(I,J)+RFR(K)
                  ELSE IF(IG(I,J).EQ.0)THEN
                        IDG(I,J)=0
                  END IF
310         CONTINUE
320      CONTINUE
330 CONTINUE
      DO 345 I=1,10
         WRITE(17,343) (RF(J,I),J=1,11)
343      FORMAT(11(2X,F5.2))
345 CONTINUE
      DO 347 I=1,10
         NUV(I)=0
         NUB(I)=0
347 CONTINUE
      M=0
      DO 355 I=1,10
      TOTS=0.0
         M=M+1
         DO 350 J=1,10
         IF(NUB(I).GT.0)THEN
               NLB(I)=IG(I,J)
               GOTO 355
         END IF
         TOTS=TOTS+RF(I,J)
         IF(TOTS.GT.4.5)THEN
               NUB(I)=IG(I,J)
         END IF
350      CONTINUE
355 CONTINUE
```

```
      M1=700
      DO 365 J=1,10
      M1=M1+20
         DO 360 K=1,53
         IF(N(K).EQ.NUB(J))THEN
                NUV(J)=IH(K)
         END IF
         IF(N(K).EQ.NLB(J))THEN
                NLV(J)=IH(K)
         END IF
360     CONTINUE
         NVC(J)=(NUV(J)-NLV(J))/2
         NVC(J)=NVC(J)+NLV(J)
         NLC(J)=M1
         NRC(J)=M1+20
365 CONTINUE
      DO 375 J=1,10
         WRITE(17,370) NLC(J),NVC(J),NRC(J),NVC(J)
370     FORMAT(4(2X,I3))
375 CONTINUE
      DO 385 I=1,10
         X=0.0
         DO 380 J=1,10
         IF(NIG(I,J).GT.NVC(I))THEN
                IF(RF(I,J).GT.X)THEN
                X=RF(I,J)
                NRR(I)=IG(I,J)
                RFN(I)=RF(I,J)
                END IF
         END IF
380     CONTINUE
385 CONTINUE
      DO 395 I=1,10
         DO 390 J=1,53
         IF(NRR(I).EQ.N(J))THEN
         NRIH(I)=IH(J)
         NRIV(I)=IV(J)
         END IF
390     CONTINUE
395 CONTINUE
      DO 398 I=1,10
         WRITE(17,397) NRR(I),RFN(I),NRIV(I),NRIH(I)
397     FORMAT(2X,I2,2X,F5.2,2X,I3,2X,I3)
398 CONTINUE
      STOP
      END
```

APPENDIX C

UPDATED LIST OF NODES AND ARCS

This appendix contains the updated list of nodes and arcs after "dummy" nodes have been added to the network. This list is the result of eliminating the arcs which were not feasible, and also those eliminated due to generating a connected network. In addition the lists of nodes and arcs contain the "dummy" nodes generated, along with the new arcs that result from adding these nodes. The following variables are used for nodes i and the node characteristics:

N_i	An integer node identification number.
NV_i	A three digit latitudinal coordinate.
NH_i	A three digit longitudinal coordinate.

N_i	NV_i	NH_i	N_i	NV_i	NH_i
61	930	327	28	822	325
62	930	312	34	789	333
1	936	293	35	804	330
2	906	350	36	787	313
3	910	328	37	798	277
4	908	310	38	789	270
5	915	285	39	793	267
6	902	278	40	798	263
7	902	315	41	786	258
8	884	353	43	764	332
9	875	335	44	764	324
10	883	300	45	766	301
11	878	287	46	773	253
12	870	300	51	759	234
13	868	268	52	747	238
14	867	365	53	739	238
15	865	362	54	745	249
16	853	335	55	743	285
17	843	320	56	733	328

18	843	302	57	722	314
20	853	273	60	733	242
21	833	273	63	885	273
24	817	292	64	888	325
25	830	300	65	868	344
26	833	310	66	851	286
27	819	313	67	748	330
68	743	319			

The following variables are used to describe arc characteristics for each arc j.

H_j Head node identification number.
T_j Tail node identification number.
RF_j Flow rate of the arc (battalions per hour).

H_j	T_j	RF_j	H_j	T_j	RF_j
61	3	1.67	25	27	1.67
62	4	1.67	26	25	1.67
1	5	1.67	26	27	1.67
2	8	1.67	26	28	1.67
3	2	1.67	27	24	1.67
3	8	2.50	27	36	0.83
4	3	1.67	28	35	1.67
4	7	1.67	34	43	0.83
5	4	1.67	35	36	0.83
5	6	1.67	36	34	1.67
6	10	1.67	36	44	0.83
6	63	1.67	37	40	1.67
7	10	1.67	37	39	1.67
7	64	1.67	37	38	1.67
8	14	0.83	38	45	0.83
8	15	0.83	39	40	0.83
8	9	1.67	40	41	1.67
8	65	1.67	41	46	1.33
9	16	1.67	43	44	1.67
10	11	1.67	43	67	1.67

11	12	1.67	44	68	1.67
12	18	1.67	45	44	0.83
12	20	1.67	46	51	1.67
12	66	1.67	51	52	1.67
13	20	1.67	52	53	0.83
14	15	0.83	52	54	1.67
15	16	0.83	53	54	1.67
16	17	0.83	54	60	1.67
17	28	0.83	54	55	1.67
18	25	0.83	55	57	0.83
18	26	1.67	56	57	1.67
18	21	1.67	63	13	1.67
20	21	1.67	64	9	1.67
21	25	1.67	65	16	1.67
24	37	0.83	66	21	1.67
24	36	2.50	67	56	1.67
25	24	1.67	68	57	1.67

APPENDIX D

COMPUTER PROGRAMS FOR THE PLANNING MODEL

This appendix contains the computer progam used to support the algorithms in Chapter 4. This program contains the representative parts of the original program used to support the example in Chapter 4.

```
      INTEGER TX(5),X(5),Y(5),TY(5)
      DIMENSION URX(5,5),SPEDX(5),DISTX(5),BIPX(5),STATEX(5),XK(5)
      DIMENSION SIP(5,81)
      INTEGER DISX(5,81)
      INTEGER DISY(5,81)
      DIMENSION MX(5)
      DIMENSION URY(5,5),SPEDY(5),DISTY(5),BIPY(5),STATEY(5),YK(5)
      DIMENSION SIPY(5,81)
      DIMENSION MY(5)
      DIMENSION SIPT(5),SIPTY(5)
      DIMENSION ABIPX(5),STATX(5),COEFX(5),XNX(5),BRX(5)
      DIMENSION ABIPY(5),STATY(5),COEFY(5),YNY(5),BRY(5)
      DIMENSION IBUFY(5),IBUX(5)
      DIMENSION SIPSUM(81),SIYSUM(81),DIFF(81)
      DIMENSION DIFFN(81),SXNSUM(81)
      DIMENSION NOT(5,5)
      DIMENSION ATT(5,5),ATY(5,5)
      CALL EXCMS ('FILEDEF 21 DISK FILE ALAR1 A1 (PERM')
      OPEN(UNIT=23,FILE='ALAR3')
      OPEN(UNIT=24,FILE='ALAR4')
      OPEN(UNIT=25,FILE='ALAR5')
      OPEN(UNIT=26,FILE='ALAR6')
      CALL EXCMS ('FILEDEF 35 DISK FILE ALOU5 A1 (PERM')
      CALL EXCMS ('FILEDEF 38 DISK FILE ALOU8 A1 (PERM')
      CALL EXCMS ('FILEDEF 39 DISK FILE ALOU9 A1 (PERM')
      DO 2 I=1,5
        READ(21,4)X(I),MX(I),TX(I),BIPX(I),SPEDX(I),DISTX(I),STATEX(I),
     1  XK(I)
    2 CONTINUE
      DO 3 J=1,5
        READ(23,4)Y(J),MY(J),TY(J),BIPY(J),SPEDY(J),DISTY(J),STATEY(J),
     1  YK(J)
    3 CONTINUE
    4 FORMAT(1X,3(I1,1X),F4.0,1X,F4.1,1X,F4.1,1X,F4.2,1X,F1.0)
      DO 7 I=1,5
         READ(24,6) NOT(I,1),NOT(I,2),NOT(I,3),NOT(I,4),NOT(I,5)
    6    FORMAT(2X,4(I2,1X),I2)
    7 CONTINUE
      DO 9 I=1,5
         READ(25,8) ATT(I,1),ATT(I,2),ATT(I,3),ATT(I,4),ATT(I,5)
    8    FORMAT(2X,4(F3.2,1X),F3.2)
    9 CONTINUE
      DO 11 I=1,5
         READ(26,10) ATY(I,1),ATY(I,2),ATY(I,3),ATY(I,4),ATY(I,5)
   10    FORMAT(2X,4(F3.2,1X),F3.2)
   11 CONTINUE
      DO 12 K=1,80
         SIPSUM(K)=0.0
   12 CONTINUE
```

This part of the program represents that part of the code used to generate the situational inherent power curves for the blue entities (variables which end in an X) and the red entities (those ending with a Y).

```
      DO 55 I=1,5
      CALL ABIPC(STATEX(I),BIPX(I),DISTX(I),XK(I),SPEDX(I),ABIPX(I),
     1BRX(I))
      BUF=0.0
      BUF=DISTX(I)/SPEDX(I)
      BUFX=BUF*10.0
      IBUF=BUFX
         SX=XK(I)
           MI=MX(I)
      T=0
      BUY=0.0
      IF(TX(I).EQ.0)THEN
      DO 50 K=1,80
         S=K
         S=S*.1
         IF(K.LE.IBUF)THEN
              DISX(I,K)=IBUF-K
         ELSE
              DISX(I,K)=0
         END IF
         IF(K.EQ.1)THEN
            SIP(I,K)=ABIPX(I)
         ELSE IF(K.LT.IBUF)THEN
            SIP(I,K)=ABIPX(I)*(2.71828**(BRX(I)*S))
         ELSE IF(K.EQ.IBUF)THEN
            SIP(I,K)=BIPX(I)*XK(I)
            SIPT(I)=SIP(I,IBUF)
            T=S
         ELSE
            SIP(I,K)=SIPT(I)*(2.71828**(-.01*(S-T)))
         END IF
   50 CONTINUE
      ELSE
         DO 52 J=1,5
         IF(TX(I).NE.J)GOTO 52
              BUY=DISTY(J)/SPEDY(J)
              BUFY=BUY*10.0
              IBUFY(I)=IFIX(BUFY)
   52    CONTINUE
      DO 53 K=1,80
         S=K
         S=S*.1
         IF(K.LE.IBUF)THEN
              DISX(I,K)=IBUF-K
         ELSE
              DISX(I,K)=0
         END IF
         IF(K.EQ.1)THEN
            SIP(I,K)=ABIPX(I)
         ELSE IF(K.LT.IBUF)THEN
            SIP(I,K)=ABIPX(I)*(2.71828**(BRX(I)*S))
         ELSE IF(K.EQ.IBUF)THEN
            SIP(I,K)=BIPX(I)*XK(I)
            SIPT(I)=SIP(I,IBUF)
            T=S
         ELSEIF((K.GT.IBUF).AND.(K.LE.IBUFY(I))) THEN
            SIP(I,K)=SIPT(I)*(2.71828**(-.01*(S-T)))
         ELSE
            ATTX=.20
            SIP(I,K)=SIPT(I)*(2.71828**(-ATTX*(S-T)))
         END IF
   53 CONTINUE
      END IF
```

```
 55 CONTINUE
      DO 100 K=1,80
         WRITE(UNIT=35,FMT=60) K,DISX(1,K),SIP(1,K),DISX(2,K),SIP(2,K),
     1DISX(3,K),SIP(3,K),DISX(4,K),SIP(4,K),DISX(5,K),SIP(5,K)
 60      FORMAT(I2,5(2X,I2,2X,F7.2))
100 CONTINUE
      DO 140 K=1,80
         SIYSUM(K)=0.0
140 CONTINUE
      DO 155 J=1,5
      CALL ABIYC(STATEY(J),BIPY(J),DISTY(J),YK(J),SPEDY(J),ABIPY(J))
     1BRY(J))
      BUYF=0.0
      BUYF=DISTY(J)/SPEDY(J)
      BUFF=BUYF*10.0
      IBUY=IFIX(BUFF)
         SY=YK(J)
            MI=MY(J)
      T=0
      BUX=0.0
      IF(TY(J).EQ.0)THEN
      DO 150 K=1,80
         S=K
         S=S*.1
         IF(K.LE.IBUY)THEN
                DISY(J,K)=IBUY-K
         ELSE
                DISY(J,K)=0
         END IF
         IF(K.EQ.1)THEN
             SIPY(J,K)=ABIPY(J)
         ELSE IF(K.LT.IBUY)THEN
             SIPY(J,K)=ABIPY(J)*(2.71828**(BRY(J)*S))
         ELSE IF(K.EQ.IBUY)THEN
             IF(J.EQ.1)THEN
                SIPY(J,K)=3000.0
             ELSE IF(J.EQ.2)THEN
                SIPY(J,K)=3000.0
             ELSE IF(J.EQ.5)THEN
                SIPY(J,K)=100.0
             END IF
             SIPTY(J)=SIPY(J,IBUY)
             T=S
         ELSE
             SIPY(J,K)=SIPTY(J)*(2.71828**(-.03*(S-T)))
         END IF
150 CONTINUE
      ELSE
         DO 152 I=1,5
         IF(TY(J).NE.I)GOTO 152
                BUX=DISTX(I)/SPEDX(I)
                BUXF=BUX*10.0
                IBUX(J)=IFIX(BUXF)
152     CONTINUE
      DO 153 K=1,80
         S=K
         S=S*.1
         IF(K.LE.IBUY)THEN
                DISY(J,K)=IBUY-K
         ELSE
                DISY(J,K)=0
         END IF
         IF(K.EQ.1)THEN
             SIPY(J,K)=ABIPY(J)
         ELSE IF(K.LT.IBUY)THEN
             SIPY(J,K)=ABIPY(J)*(2.71828**(BRY(J)*S))
         ELSE IF(K.EQ.IBUY)THEN
             SIPY(J,K)=BIPY(J)*YK(J)*STATEY(J)
             SIPTY(J)=SIPY(J,IBUY)
```

```
              T=S
          ELSEIF((K.GT.IBUY).AND.(K.LE.IBUX(J))) THEN
              SIPY(J,K)=SIPTY(J)*(2.71828**(-.05*(S-T)))
          ELSE
              ATTY=.20
              SIPY(J,K)=SIPTY(J)*(2.71828**(-ATTY*(S-T)))
          END IF
153   CONTINUE
        END IF
155   CONTINUE
        DO 157 K=1,80
        WRITE(UNIT=35,FMT=156) K,DISY(1,K),SIPY(1,K),DISY(2,K),SIPY(2,K),
     1DISY(3,K),SIPY(3,K),DISY(4,K),SIPY(4,K),DISY(5,K),SIPY(5,K)
156      FORMAT(I2,5(2X,I2,2X,F7.2))
157   CONTINUE
```

This portion of the code computes the overall SIP for the red and blue forces.

```
      DO 170 K=1,80
          DO 160 I=1,5
                  SIPSUM(K)=SIPSUM(K)+SIP(I,K)
160      CONTINUE
          DO 161 J=1,5
                  SIYSUM(K)=SIYSUM(K)+SIPY(J,K)
161      CONTINUE
          DIFF(K)=SIPSUM(K)-SIYSUM(K)
          WRITE(UNIT=35,FMT=165) K,SIPSUM(K),SIYSUM(K),DIFF(K)
165      FORMAT(2X,I2,2X,F8.2,2X,F8.2,2X,F8.2)
170   CONTINUE
```

This portion of the code determines feasibility of the plan based on whether a unit is commited or not. If it is commited it will have a target TX or TY.

```
      DO 205 L=5,20,5
      DO 200 K=L,80,5
          SXNSUM(K)=0.0
          DO 180 I=1,5
          IF(TX(I).EQ.0)THEN
                  IF(K.EQ.L)THEN
                          SXNSUM(K)=SXNSUM(K)+SIP(I,1)
                  ELSE
                          SXNSUM(K)=SXNSUM(K)+SIP(I,(K-L))
                  END IF
          ELSE
                  SXNSUM(K)=SXNSUM(K)+SIP(I,K)
          END IF
180      CONTINUE
          DIFFN(K)=SXNSUM(K)-SIYSUM(K)
          IF(DIFFN(K).GE.-1000.0)GOTO 181
                  IFLAG=1
                  IST=20
                  IL=0
                  POWDF=DIFFN(K)+1000.0
181      WRITE(38,185) K,SXNSUM(K),SIYSUM(K),DIFFN(K)
185      FORMAT(2X,I2,3(2X,F8.2))
200   CONTINUE
205   CONTINUE
```

If the difference in power between red and blue exceeded the tolerance threshold then the earliest time of infeasibility is designated as the decision point. Based on this time the uncommitted units are then committed against possible targets to produce the different courses of action.

```
      OPRAT=0.0
      DO 250 L=0,IST,5
```

```
      DO 240 I=3,5
          TT=(DISTX(I)/SPEDX(I))*10.0
          IT=IFIX(TT)
          DO 230 M=1,5,4
             IF(NOT(I,M).EQ.0)GOTO 230
             IF((NOT(I,M)+L).GT.IST)GOTO 240
             DO 220 J=3,4
                  DO 210 K=1,80
                     S=K
                     S=S*.1
                     ST=L
                     ST=ST*.1
                     SS=S-ST
                     IF((K+L).GT.80)GOTO 211
                     IF((K.LE.L).OR.(K.EQ.1))THEN
                          SIP(I,K)=ABIPX(I)
                     ELSE IF((K.GT.L).AND.(K.LT.(IT+L)))THEN
                          SIP(I,K)=ABIPX(I)*(2.71828**(BRX(I)*SS))
                     ELSE IF(K.EQ.(IT+L))THEN
                          SIP(I,K)=BIPX(I)*XK(I)
                          ITT=IT+L
                          SIPT(I)=SIP(I,ITT)
                          T=SS
                     ELSE
                          SIP(I,K)=SIPT(I)*(2.71828**(-ATT(I,J)*(SS-T)))
                     END IF
210            CONTINUE
                     PRINT *, I,J
211            TTY=(DISTY(J)/SPEDY(J))*10.0
                  IYY=IFIX(TTY)
                  DO 212 K=1,80
                     S=K
                     S=S*.1
                     ST=L
                     ST=ST*.1
                     SS=S-ST
                     IF(K.EQ.1)THEN
                          SIPY(J,K)=ABIPY(J)
                     ELSE IF(K.LE.(IT+L))THEN
                          SIPY(J,K)=ABIPY(J)*(2.71828**(BRY(J)*S))
                     ELSE IF((K.GT.(IT+L)).AND.(K.LE.IYY))THEN
                       IF(I.EQ.5)THEN
      SIPY(J,K)=ABIPY(J)*(2.71828**((BRY(J)*S)-(ATY(I,J)*(SS+.001))))
                       ELSE
                       SIPY(J,K)=ABIPY(J)*(2.71828**((BRY(J)-ATY(I,J))*S))
                       END IF
                     ELSE IF(K.EQ.IYY)THEN
                     SIPY(J,K)=ABIPY(J)*(2.71828**((BRY(J)-ATY(I,J))*S))
                          SIPTY(J)=SIPY(J,IYY)
                          T=S
                     ELSE
                       SIPTY(J)=SIPY(J,IYY)
                       SIPY(J,K)=SIPTY(J)*(2.71828**(-ATY(I,J)*(S-T)))
                     END IF
212            CONTINUE
    DO 214 K=1,80
       WRITE(UNIT=35,FMT=213) K,J,SIPY(J,K),I,SIP(I,K),BRX(I)
213    FORMAT(I2,2X,I2,2X,F7.2,2X,I2,2X,F7.2,2X,F6.4)
214 CONTINUE
```

This portion of the code determines the course of action with the highest ratio of red power destroyed to blue power used.

```
      IX=20
      NA=IT+L
      DIFFX=(BIPX(I)*XK(I))-(SIP(I,IX)-1.01)
      DIFFY=BIPY(J)-(SIPY(J,IX)-1.001)
      DIF=DIFFY-DIFFX
```

```
      RAT=DIFFY/DIFFX
      IF(RAT.GT.OPRAT)THEN
          OPRAT=RAT
          JO=J
          IO=I
          NO=L
          NOP=NA
      END IF
      PRINT *, OPRAT,JO,IO,NO,NOP
      WRITE(39,215) NA,I,J,DIFFY,DIFFX,DIF,RAT
215   FORMAT(1X,I2,2X,I1,2X,I1,2X,F8.3,2X,F8.3,2X,F9.3,2X,F9.3)
220 CONTINUE
230 CONTINUE
240 CONTINUE
250 CONTINUE
     STOP
     END
```

The following subroutines compute the ABIP of the red and blue entities as well as the rate of power increase.

```
      SUBROUTINE ABIPC(STATEX,BIPX,DISTX,XK,SPEDX,ABIPX,BRX)
      STATX=SQRT(STATEX)
      ABIPX=BIPX*XK*(DISTX**(-1.0))*STATX
      COEFX=(BIPX*XK)*(ABIPX**(-1.0))
      XNX=ALOG(COEFX)
      BUF=DIST/SPED
      BUFX=BUF*10.0
      IBUF=IFIX(BUFX)
      BRX=XNX/BUF
      RETURN
      END
      SUBROUTINE ABIYC(STATY,BIY,DITY,YYK,SPDY,ABPY)
      STATY=SQRT(STATY)
      ABPY=BIY*YYK*(DITY**(-1.0))*STATY
      COEFY=(BIY*YK)*(ABPY**(-1.0))
      YNY=ALOG(COEFY)
      BUYF=DITY/SPDY
      BUFF=BUYF*10.0
      IBUY=IFIX(BUFF)
      BY=YNY/BUYF
      RETURN
      END
```

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